MTT REPORT 50

From Waste to Traffic Fuel -projects

Final report

Saija Rasi, Eeva Lehtonen, Esa Aro-Heinilä, Jukka Höhn, Hannu Ojanen, Jouni Havukainen, Ville Uusitalo, Kaisa Manninen, Erja Heino, Nea Teerioja, Reetta Anderson, Ville Pyykkönen, Saana Ahonen, Sanna Marttinen, Sanna Pitkänen, Maarit Hellstedt and Jukka Rintala

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Headline

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Abstract

The main objective of the project was to promote biogas production and its use as traffic fuel. The aims in the four Finnish and two Estonian case regions were to reduce the amount and improve the sustainable use of waste and sludge, to promote biogas production, to start biogas use as traffic fuel and to provide tools for implementing the aims.

The results of this study show that achieving the food waste prevention target will decrease greenhouse gas emissions by 415 000 CO_2-eq tons and result in monetary savings for the waste generators amounting to almost 300 €/capita on average in all case regions in 2020. The results show that waste prevention should be the first priority in waste management and the use of waste materials as feedstock for energy production the second priority.

In total 3 TWh energy could be produced from available biomass in the studied case regions. This corresponds to the fuel consumption of about 300 000 passenger cars. When a Geographical Information System (GIS) was used to identify suitable biogas plant site locations with particular respect to the spatial distribution of available biomass, it was found that a total of 50 biogas plants with capacity varying from 2.1 to 14.5 MW could be built in the case regions. This corresponds to 2.2 TWh energy and covers from 5 to 40% of the passenger car fuel consumption in these regions.

Using all produced biogas (2.2 TWh energy) for vehicle fuel GHG emissions would lead to a 450 000 t CO_2-eq reduction. The same effect on emissions would be gained if more than 100 000 passenger cars were to be taken off the roads. On average, the energy consumed by biogas plants represents approximately 20% of the produced energy.

The results also show that biomethane production from waste materials is profitable. In some cases the biomethane production costs can be covered with the gained gate fees. The cost of biomethane production from agricultural materials is less than 96 €/MWh_{th}, meaning that biomethane production from agricultural materials is profitable after the biomethane demand has become established. It is also notable that if the trend in biomethane consumption follows a 10% growth path, employment could increase from 84 to 178% depending on the studied case region.

Keywords:

biomethane, biogas, vehicle fuel, public transport, greenhouse gases

Foreword

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 wastes and by-products in the target regions. The aim was also to provide tools for implementing and aims to raise awareness of the environmental, economical and regional effects of waste prevention and biogas traffic fuel use.

For four case regions in Finland and two case regions in Estonia, a biowaste and sludge prevention plan, a biogas production plan and a plan for the use of biogas use as traffic fuel were drafted. The four Finnish case areas were Turku, Salo, Helsinki and Kymenlaakso regions and two case regions in Estonia were Harju- and Lääne-Viru Counties. The environmental and economic impacts of the plans were compared to the situation in year 2020, when the biomass collection and treatment are handled either in same way as they are now or as planned in the region.

The project is funded by EU Central Baltic Interreg IV A Programme and Regional Council of Southwest Finland. The project partners were Finland Agrifood Research Finland, HSY Helsinki Region Environmental Services Authority, TUT Tallinn University of Technology, SEI-T Stocholm Environment Institute and Ministry of Environment, Tallinn Environment Board, Lääne-Viru County Goverment, OÜ Mõnus Minek SEES, AS Terts, Baltic Biogas OÜ, Turun seudun jätehuolto Oy, Kymen Vesi Oy, Kymenlaakson Jäte Oy, Rouskis Oy, Liikelaitos Salon Vesi and Finnish Biogas Assosiation.

This report contains results from Finnish case regions. All publications from this project can be found from www.wfuel.info.

Content

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 Waste to fuel 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 wastes and by-products in the target regions. Available biowastes, 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, a biogas production plan and a plan for the use of biogas as traffic fuel were drafted.

The four Finnish case regions were Turku, Salo, Helsinki and Kymenlaakso. About 1/3 of the Finnish population lives in the case regions covered by these studies. The regions consist of both agricultural areas and built-up city areas (Fig 1).

The Turku region covers 14 municipalities, 324 000 residents and 19 000 summer cottages. The Salo region has four municipalities, 75 000 inhabitants and 20 000 summer residents coming from outside the region. The Helsinki region consists of five municipalities – Helsinki, Espoo, Vantaa, Kirkkonummi and Kauniainen – with a total population of 1.1 million. The Kymenlaakso region consists of eight municipalities with 186 000 residents (Table 1, Fig. 1). The agricultural land area covers from 9 to 26% of the total land area, depending on the region; this land area roughly indicates the potential for energy crop cultivation.

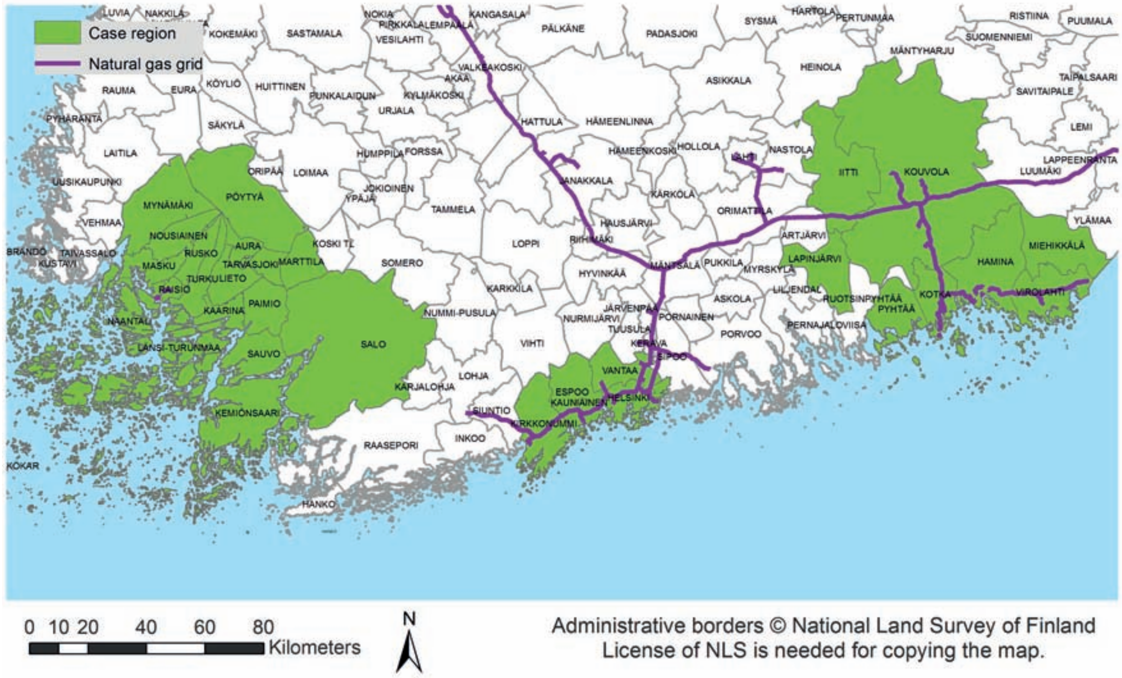

Figure 1. Case regions.

Table 1. Description of the case regions.

		Turku region	Salo region	Helsinki region	Kymenlaakso region
Population 2009		325 600	75 600	1 070 000	185 500
Population prediction 2020		344 200	80 800	1 178 000	182 000
Area	km^2	4 000	3 200	1 186	5 900
Field area 2009	Ha	98 400	84 000	10 783	95 300
Share of field area of total area	%	25	26	9	16

1.2 Waste prevention

Wastes are 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:

a. the quantity of waste, including the re-use of products or the extension of life span of products;
b. the adverse impacts on the environment and human health of the waste generated; or
c.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 unneccessarily. 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-emissios, 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, etc., 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. Finland's prevention plan is part of the national waste plan, which sets a prevention target only for municipal waste: to freeze the amount of municipal waste by 2016 to the level of the first years of 2000, which was 2.3 – 2.5 million tons, and then to start reducing this amount. There are no targets for sludge prevention in the national waste plan (Ministry of the Environment 2008).

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 nonexistent. Targets and measures, if any, are set mainly only to promote the recovery and recycling of waste.

1.3 Biogas production and use in vehicle fuel

Biogas (main components: methane and carbon dioxide) is produced by micro-organisms from biodegradable organic material under anaerobic conditions from materials such as biowastes, 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 (Fig 2). 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).

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.

Biomethane- and methane-fuelled vehicles
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 about 80 are busses (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, par-

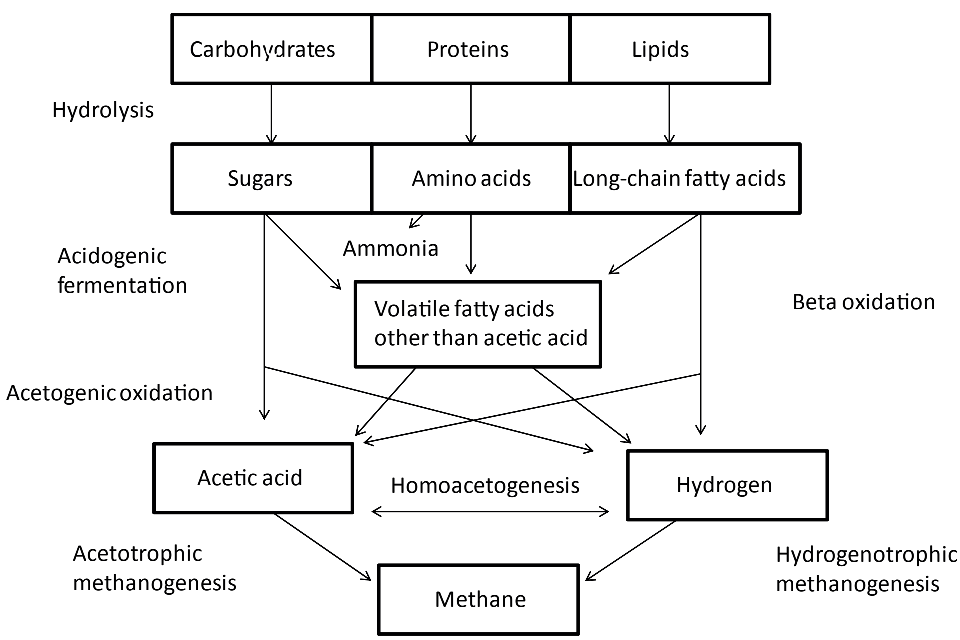

Figure 2. Anaerobic degradation of organic matter (Mata-Alvarez 2003).

ticles 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 (NGV 2011). However, compared to the total number of vehicles that have access to methane refuelling, their share is still very limited, less than 1% in all countries.

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 (NGV 2011).

1.4 Environmental impact assessment

The aim of an LCA is to address the environmental impact of a product during its life cycle, from cradle to grave, such that the LCA takes into account the impacts of manufacturing the raw material used, disposal and recycling (SFS-EN ISO 14040; 2006). LCAs typically take into account the environmental aspects and impacts, while typically excluding the economic and social aspects and impacts (Koskela et al. 2010). The LCA methodology is standardised according to SFS-EN ISO standards 14040 and 14044.

A food product has several production phases and thus several emissions sources. Food wastes are often found to be also suitable for biogas production. The life cycle of a food product can be divided into six different main phases as shown in Figure 3. Transports and possible storing between the phases can be considered to be sub-phases. In every phase, resources (e.g. energy) are needed and emissions and waste are generated.

The LCA of the biomethane fuel product covers the phases of raw material production and extraction, processing, transportation, manufacturing, storage, distribution and use. In assessing the sustainability of the product' s whole fuel chain (cradle-to-grave), the LCA appears to be a useful tool (Soimakallio, Antikainen & Thun 2009, Finnveden et al. 2009).

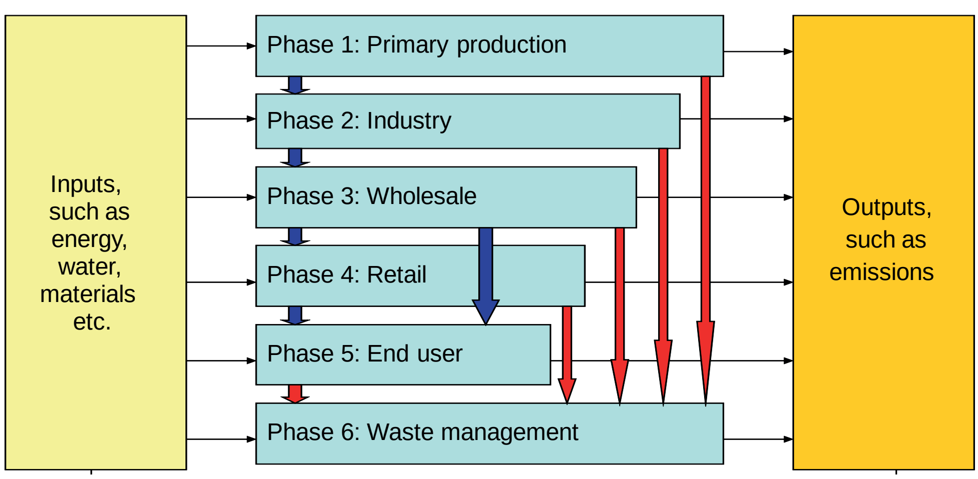

Figure 3. Life cycle of a food product. Transports and possible storing between the phases are marked as thick arrows and can be considered as sub-phases. The blue and red arrows indicate that transport occurs before or after the product has turned into waste, respectively.

2 Materials and methods

2.1 Origin of data

2.1.1 Feedstocks for biogas production

2.1.1.1 Biowaste

This study considered biowaste produced in households, public and private services, retail and industry. Information on waste amounts was obtained from different statistics and studies (Roström & Uggeldahl 2003, Uggeldahl 2010, Anderson 2010, Martti 2010, PETRA[1] 2010) and by interviewing large industrial companies.

Households, public and private services

Biowaste in this study consists of biowaste generated in households and in public (schools, kindergartens, hospitals, other care facilities/nursing homes, universities and vocational schools) and private (restaurants, hotels, retail, ferryboats) services. The biowaste amounts include both kitchen and garden waste. A higher figure for biowaste per capita was used for households in Helsinki than for the other three regions based on studies in Helsinki and Turku (Roström & Uggeldahl 2003, Uggeldahl 2010, Anderson 2010). The amount of biowaste per capita was assumed to be the same in Salo and Kymenlaakso as the figure determined for Turku. For public and private services, the nominal amounts of mixed waste and biowaste per employee/customer/student, etc. have been calculated based on data concerning different sectors from the PETRA -waste benchmarking system. The share of mixed waste accounted for by biowaste from hospitals, retail, restaurants and hotels is based on the 2008 study by YTV and the amounts of biowaste in other services are based on the assumption that mixed waste in these sectors includes 40 % biowaste (Table 2).

Table 2. The amounts of biowaste generated in households and in public and private services used in this study (for the year 2009) and the origin of the information.

		Biowaste	Origin of data
Households			
Household biowaste in Turku, Salo and Kymenlaakso	kg/capita/a	83	1
Household biowaste in Helsinki	kg/capita/a	100	2
Public services			
Schools	kg/students and employees/a	23	3
Daycares	kg/customers and employees/a	50	3
Hospitals	kg/customers and employees/a	108	3
Other nursing homes	kg/customers and employees/a	256	3
Universities and vocational schools	kg/students and employees/a	19	3
Private services			
Restaurants and hotels	kg/employees/a	1033	3
Retail	kg/employees/a	2089	3
Ferries	kg/passenger/a	0.2	4

1 Roström & Uggeldahl 2003, Uggeldahl 2010
2. Anderson 2010, Martti 2010
3. Statistics and the PETRA-waste benchmarking system; 4. Local shipping company

Waste amounts in 2020

The total waste amounts in households in the year 2020 were calculated (e.g. Ehrlich & Holdren, 1971, Chertow 2001, Sokka et al. 2007, Moliis et al. 2009) using municipal-level population change forecasts 2009-2020 (Statistics Finland 2009a), gross domestic product (GDP) per capita, statisticsand forecasts (Statistics Finland 2011, Poncet 2006, Rouvinen et al. 2007). The expected impact of technology changes on waste generation (waste/GDP) was expected to be on a par with the average for the previous ten-year period (1998-2008) (Statistics Finland 2009b), which was -1.3, representing a subtle decoupling of waste composition from economic growth. The technology change represents a decoupling factor that refers to the ability of an economy to grow without corresponding increases

1 PETRA is a waste data bank in which, companies and organisations in the Helsinki region can voluntarily report their yearly amounts and treatment of different waste fractions (e.g. biowaste and mixed waste).

in environmental pressure, here biowaste generation (waste/GDP). Short-term growth in GDP is based on the Research Institute of the Finnish Economy's (ETLA) forecast, 3.5 % for the years 2010-2011 (ETLA 2010). Longer-term growth expectations are based on the forecast of the Research Center in International Economics (SEPII) and ETLA 2.1% yearly (Poncet 2006, Rouvinen et al. 2007). Expected population changes are taken from municipal-level population change forecasts for 2009-2020 (Statistics Finland 2009a).

For public services and retail the amounts of biowaste for 2020 were forecast using the estimated number of people in a given population group who are likely to use the services. The forecasted municipal-level 2020 population (Statistics Finland 2009a) was divided into age groups representing the users of the services (kindergartens (0-6 years), primary schools (7-15 years), high school and vocational school (16-18 years), universities and vocational schools (19-25 years), and old-age homes (above 75 years)), while all inhabitants independent of age were assumed to use hospital services. The 2020 biowaste amounts were extrapolated by multiplying the waste amount (kg biowaste per capita per year) with the number of people in each group of service users. In most cases the usage of school and education services is decreasing slightly (except for the Salo region); meanwhile old-age homes and other caring facilities are growing substantially (31-39%).

The usage of restaurant and hotel services (meal servings) per person varies regionally and use clearly increases with growth in GDP (according to the statistics for the 2000s (ACNielsen 2005, ACNielsen 2008)). Thus, the year 2020 situation was evaluated in terms of economic growth and taking regional differences into account. With the expected GDP growth rate (short term 3.5% and long term 2.1%) the average usage of restaurant and hotel meal servings per person will grow by 1.5% yearly and the amount of biowaste is expected to grow correspondingly.

Biowaste composition

The composition of biowaste from households and the public and private sector was divided into food waste, tissue papers, garden waste and other waste, which is the residual material fraction including, e.g. newspapers and biodegradable plastic bags that do not belong in biowaste (Toukola et al 2011, Pelli 2011, YTV 2008, Jokinen 2005) (Table 3). Moreover, the food waste was divided into edible and inedible food waste (Silvennoinen et al. 2012, Toukola et al. 2011, Pelli 2011).

Table 3. The composition of biowaste in households and the public and private sector (% of mass)

	Households	Public sector	Retail	Private sector, retailexcluded
Food waste	73%	77%	95%	80%
Edible food waste	23%	61%	Irrelevant, all equally avoidable	62%
Inedible food waste	50%	16%		18%
Tissue papers (dry)	3%	10%	1%	6%
Garden waste	22%	11%	0%	5%
Other	2%	3%	3%	10%

Industrial biowaste

The current amounts of biowaste, expected changes and measures for waste prevention in industries in the Turku, Salo and Kymenlaakso regions were sourced by interviewing the presumably largest industrial biowaste producers such as bakeries, slaughterhouses, food processing plants and pulp and paper mills. Information on waste amounts was also based on the terms and conditions of the waste environmental permits of the industries. The amount of biowaste from industry in the Helsinki region was sourced from the accounting system of material flows (Martti 2010). The amount of industrial biowaste in 2020 was assumed to stay in 2009 level.

2.1.1.2 Sludges

Sludge data was gathered from municipal sewage treatment plants, from industry and industrial wastewater treatment plants and from wastewater treatment facilities in sparsely populated areas. The amount of sludge at municipal and industrial waste water treatment plants was obtained from the annual reports of the plants (municipal plants) and from the representatives of the treatment plants and/or companies. The treated sludge amounts and produced biogas amounts in the Helsinki region were taken from existing reports and plans (HSY 2010, Sundell 2010).

Sludge from sparsely populated areas was included in the amount of sludge from municipal wastewater treatment plants as most of the sludge from sparsely populated areas is transported to municipal wastewater treatment plants. It was assumed that the population not connected to the sewer network in 2009 would be connected to the network by 2020. The population figures for 2009 and the estimate of the situation in 2020 were gathered from the wastewater treatment plants. The figure used for sludge per inhabitant was 850 l/a (TS 3%) (Länsi-Suomen ympäristökeskus 2009).

In addition, the amount of sludge from vacation houses was considered by estimating that 10 % of the houses have an indoor toilet (Valtioneuvoston asetus 2003), that each family member spends 10% of the year at the vacation house (TemaNord 2003) and that the average family size is 2.1 persons. The number of vacation houses in the study regions was obtained from the regional waste plan of South and West Finland 2009, and the amount of sludge was assumed to be the same in 2020 as it was in 2009.

2.1.1.3 Manure

The excrements produced by cattle, swine, poultry, horses, sheep and goat farming were considered. For the calculation, these livestock were categorised by sex, age, and production type. Amounts are shown for farming systems producing solid or liquid manure.

The total amount of manure was calculated using values for the amounts of manure that can be produced per animal per year (Table 4) and the number of animals in the case regions by 2009 provided by the Agency for Rural Affairs and the Finnish Food Safety Authority Evira (2011).

In order to calculate the potential amount of excrement available for biogas production, the amount of excrement produced by animals during the pasturing period was deducted. The periods for each type of animal are assumptions (Table 5).

The amount of excrement for the year 2020 was estimated by considering the projected livestock population for 2020. The projected population was estimated using the estimated changes in domestic production of animal products in comparison with 2009. Milk and beef production was predicted to remain at the 2009 level. For pork, broiler meat and eggs the change rates were estimated to be -5.8, 35.8 and -13.2 %, respectively.

Table 4. Excrement amount per animal and year (Expert opinion).

Livestock	Liquid manure t/animal/a	Solid manure t/animal/a
Dairy cows	25.33	24.05
Suckler cows	17.96	16.86
Heifers >12,<24 months	10.02	10.87
Heifers >24 months	10.02	10.87
Bulls >12,<24 months	14.46	13.43
Bulls >24 months	14.46	13.43
Calves male (<12 months)	8.17	8.67
Calves female (<12 months)	6.08	6.57
Sows + piglets < 11 weeks	7.00	5.37
Gilts	2.40	1.63
Boars	2.40	1.63
Fattening pigs 50-110 kg	2.00	1.49
Pigs 20-50 kg	1.50	1.14
Horses		12.75
Sheeps & goats		1.50
Laying hens	0.05	0.05
Broilers		0.03
Broiler hens		0.08
Cockerels		0.09
Chickens		0.03
Turkeys		0.09

Table 5. Pasturing period, proportion of pastured animals and proportion of excreted manure on pasture for different types of livestock (Grönroos et al. 2009).

Livestock	Pasturing period (d)	Pastured animals (%)	Manure excreted on pasture (%)
Dairy cows	125	90	26
Suckler cows	140	95	36
Heifers	140	90	35
Bulls	0	0	0
Calves < 12 month	100	25	7
Pigs	0	0	0
Horses	140	95	36
Sheep	130	90	32
Goats	130	90	32
Poultry	0	0	0

2.1.1.4 *Energy crops and crop residues*

Grass was considered as the potential energy crop. Sustainable amounts of energy crops were assumed to be cultivated on crop production farms only. Crop rotation of grass was assumed with cereal in sequence of 2 seasons of grass and 3 seasons of cereals. The yield of grass silage is presented in Table 6. Amount of fields and cultivated crops were gathered from Information centre of the Ministry of Agriculture and Forest.

The amount of crop residues from crop production – e.g straw, potato waste and tops of vegetables – was considered (Kahiluoto & Kuisma 2010). Field available for straw, i.e. cereals production (Table 6), was estimated with a crop rotation approach described above.

Table 6. The used biomass yields for energy crops and crop residues (Tike 2008, Pahkala et al. 2009, Expert opinions).

	Yield (t/ha)
Silage	21.4
Straw of cereals	3
Straw of rapeseed	2
Sugar beet top	7.5
Potato waste	5
Vegetable top	7
Greenhouse waste	35

2.1.1.5 *Landfills*

The amounts of landfill gas recovered were obtained from the annual reports of the waste management companies and from the Finnish biogas plant register (Kuittinen et al. 2010). Information on estimated 2020 landfill gas recovery was obtained from the waste management companies.

2.1.2 Material characteristics

The potential biogas production feedstocks were categorised and the methane potential, total solids (TS), ratio of volatile solids (VS) and TS and the amounts of nutrients (carbon, nitrogen, phosphorus) were estimated (Table 7).

Table 7. Characteristics of materials used in the calculations (Lehtomäki 2006, Kahiluoto & Kuisma 2010, Smith & Frost 2000, Smith et al. 2000, Hietanen 2005, Ojanen, P. 2001, Elvira et al. 1996, Tuomisto 2011, Steffen et al 1998, expert opinions).

	CH4 m^3/tVS	CH4 m^3/tww	TS %	VS/TS	C %TS	N %TS	P %TS
Biowaste from households, industry, private and public services and ferries	400	97	27	90	48	2	0.4
Fish processing waste	520	119	27	85	40	10	0.2
Bakery waste	400	238	66	90	45	2.3	0.2
Milk waste (whey)	420	18	6	70	45	5	1
Sweets waste	380	325	90	95	n.k	n.k	n.k
Fat waste	800	288	40	90	73	0.4	0
Slaughtering waste	600	216	40	90	56	8	1
Vegetable waste	400	97	27	90	45	1.6	0.2
Manure of horses, etc.	250	48	32	60	45	2.5	0.9
Manure from slaughterhouses	250	18	10	70	40	8.25	1.95
Solid manure of cattle	200	23	19	60	46	2.4	0.8
Liquid manure of cattle	200	10	6	80	45	5.5	0.9
Solid manure of pigs	300	58	24	80	43	2.5	1.5
Liquid manure of pigs	300	10	4	85	30	11	3
Solid manure of poultry	300	81	38	71	38	3.1	1.5
Sludge from food industry	300	42	20	70	35	4	2.5
Sludge from paper and pulp mills, biol.	100	14	20	70	46	1.5	0.3
Sludge from paper and pulp mills, primary	300	42	20	70	25	1.2	0.1
Sludge from municipality ww- treatment	300	42	20	70	35	4	2.5
Straw of cereals	230	178	85	91	46	0.5	0.1
Vegetable top	300	28	11	85	40	2.2	0.2
Silage	350	104	35	85	47	3.4	0.6
Rapeseed straw	250	207	90	92	44.5	1.6	0.1
Reed canary grass	300	76	28	90	48	1.8	0.2

n.k. = not known, ww = wastewater

2.1.3 Biowaste treatment

The data on biowaste treatments in 2009 in the study regions was obtained from waste management companies and municipalities. In most cases precise data was not available and in these cases, some estimates were used. Biowaste used for fodder was included under waste materials even though materials used for fodder are considered to be by-products. As the calculations in this study are done for the year 2020, the materials now used in fodder production are considered to be potential biomass for biogas plants (Table 8).

Table 8. Biowaste treatment in study regions by sector in 2009.

Region	Incineration	Composting or biogas plant	Other treatment
	% of total waste		
Turku	68	28	3*
Salo	5	25	70*
Helsinki	0	44	56 *
Kymenlaakso	49	23	28**

*Landfill

** 14 % to ethanol production, 12 % for fodder, 2 % to landfill

2.1.4 Potential biomethane use

The total number of vehicles type in the case regions was obtained (Table 9, Table 10) (TraFi 2011, Jokinen 2011, Lehto 2010, Pulli 2010, Nylund et al. 2006). Biomethane can be used by all types of vehicles, and some vehicles are already operating with gaseous fuel (natural gas) in the Helsinki and Kymenlaakso regions.

Table 9. The amount of vehicles (potential biomethane users) in the case regions (TraFi 2011).

Case region	Passenger cars	Vans	Trucks	Busses	Motorbikes	Tractors	Working engines	Others
Turku	150 543	14 906	5 630	563	12 596	15 879	2 002	57 649
Salo	39 008	5457	1 745	260	3 495	9 872	712	19 390
Kymenlaakso	93 533	9 579	3 516	327	8 098	11 670	1 885	44 273
Helsinki	435 237	38 555	12 408	2 672	31 552	8 395	5 834	32 541

Table 10. Amount of waste trucks and taxis in the case regions (Jokinen 2011, Lehto 2010, Pulli 2010, Nylund et al. 2006).

Case region	Amount of taxis	Amount of waste truck (used in calculations in this study)
Turku	568	40
Salo	153	8
Kymenlaakso	308	20
Helsinki	2300	100

In the Turku region, about 166 local busses drive over 10.7 million km annually (Turun joukkoliikenne 2010). In the Kymenlaakso region, local busses operate in Kouvola and Kotka. Helsinki Region Transport has approximately 500 busses operating in the area. 44 of these busses are dual-fuel busses operating with compressed natural gas and diesel, and 43 of them are run solely on natural gas (Saari 2009).

Biomethane consumption

The amount of vehicles that could run with produced biogas was calculated. The amount of biomethane used was calculated using the gas consumption (m^3/km) of different vehicles from LIPASTO[2] and the average driving distances in 2009 (VTT 2009, Nylund et al. 2006, Nuutinen 2011) (Table 11). For passenger cars the annual average driving distance in Finland is 16 500 km/year. In this study, a higher driving distance was used based on the assumption that those who use their car more will be the first to change over to biomethane vehicles, because the profitability of a biomethane car increases as the driving distance grows.

2 LIPASTO is a calculation system for traffic, exhaust emissions and energy consumption in Finland. The system has been developed by VTT Technical Research Centre of Finland.

Table 11. Average gas consumption and driving distances used in this study (VTT 2009, Nylund et al. 2006, Nuutinen 2011)

Type of vehicle	Average driving distance (km/a)	Average gas consumption (Nm^3/100 km)
Passenger cars	30 000	6
Passenger cars owned by the City of Helsinki	7 700	6
Taxis	80 000	6
Busses on ring road routes (Helsinki region)	44 600	48
Busses on urban routes	44 600	59
Vans	20 000	10
Vans owned by the City of Helsinki	7 700	10
Trucks	26 600	59
Waste trucks	25 000	93

2.1.5 Emissions from energy production

In assessing the environmental impacts, electricity emissions were estimated for Finnish average electricity and it was assumed that heat was produced with wood chip boilers (with the exception of the Helsinki region, where it was assumed that natural gas boilers were also in use). If the produced biogas was used in heat production in the base case, then the amount of energy that needed to be compensated was produced by means of district heat in the methane case. The following emission data was used for calculations in this study: 312 g CO_2eq/kWh from average electricity produced in Finland, 220 g CO_2eq/kWh from average heat from the district heating grid and 16 g CO_2eq/kWh from heat produced from wood chips (Finnish Environment Institute 2011, Statistics Finland 2010b, Pucker et al. 2011, VAPO 2006, Motiva 2012). The data related to biogas production plant and upgrading processes is the same in every region.

2.2 Base and methane case scenarios for 2020

The environmental and economic impacts of boosted biomethane production and utilisation from biomass in the study regions for the year 2020 were assessed using the base and methane cases 2020. In these two scenarios biomass treatments in 2020 were evaluated as shown in Table 12. In waste prevention impact assessment, the scenarios are called the base and prevention cases as these phases occur before any biomethane is produced. It is assumed that the same treatment methods of biomasses are used in the base and methane cases in all four regions except for biowaste treatments in the base case (Table 13) due to differences between the regions in 2009. In the base case the amount of biowaste in 2020 was calculated using the same efficiency rate for the separate collection of biowaste as in the year 2009. Also, the prediction for population growth and its effects on waste amounts were taken into account. In the prevention and methane cases for 2020, the following assumptions were made:

a. The amount of household biowaste decreases by 30% from the year 2009.
b. The separate collection rate of biowaste for households is 65%, retail 100%, other public and private services 80% and industry 90%.

Table 12. Treatments for different materials used in the base and prevention/methane cases for year 2020.

Biomass	Treatments in the base case 2020	Treatments and used assumptions in the prevention/methanecase 2020
Biowaste from households and public and private services	Prevention of food waste is not promoted, collection and treatment are handled either in same way as they are now or as planned in the region	Waste prevention target -30%, more effective separate collection of biowaste, biomethane production
Industrial biowaste	Collection and treatment are handled either in the same way as they are now or as planned in the region	More effective separate collection of biowaste, biomethane production
Municipal sludge	Biogas production + CHP	Biomethane production. Energy from CHP production is replaced by Finnish average electricity and district heat.
Industrial sludge	Incineration	Biomethane production. The energy produced by the incineration plant is assumed to be minor
Manure	Treated in the traditional way and used in fields	Biomethane production, digestate is used in fields
Energy crops	No cultivation of energy crops	Energy crops cultivation on available land, biomethane production
By-products of plant production	Treated in the traditional way	Biomethane production
Landfill gas	CHP production and torch	Biomethane production. Energy from CHP production is replaced by Finnish average electricity and district heat.

Table 13. Biowaste treatment in the base case and assumptions in the methane case in the four study regions.

Region/waste fraction	Treatments in the base case 2020	Treatments and assumptions in the methane case 2020
Kymenlaakso		
Bakery waste	Ethanol production	Biomethane production. Ethanol is replaced with petrol. By-products are excluded.
Separately collected biowaste	Tunnel compost, compost in land-scaping	Biomethane production.
Rest of the biowaste	Burning in incineration plant	Biomethane production. Decreased energy in incineration plant is replaced by Finnish average electricity and district heat.
Turku and Salo regions		
Separately collected biowaste	Biogas production (CHP) in Forssa and tunnel compost, compost in landscaping	Biomethane production. The N_2O and CH_4 emis-sions from gas turbine are included.
Biowaste in mixed waste	Burning in incineration plant	Decreased energy in incineration plant is re-placed by Finnish average electricity and district heat.
Helsinki region		
Separately collected biowaste	80 000 t/a digested for electricity and heat production and the rest is composted	Biomethane production

2.2.1 Impact assessment of biowaste prevention

The environmental and economic effects of food waste prevention in the four case regions in the year 2020 were estimated by comparing the scenarios called the base and prevention case 2020 (Table 12). The prevention amounts were assumed to apply proportionally to all biowaste fractions (food waste, tissue papers and garden waste), but only the effects of the prevention of the most significant biowaste fraction, food waste, were taken into account.

The analysis was roughly divided into three main life cycle phases, as shown in Table 14. The effects were first defined per ton of different food waste fractions and then multiplied with the amount of waste prevented to obtain the total effects of waste prevention as planned in this project. These effects were considered as avoided effects at their full scale, which means that the waste prevention actions themselves do not cause any emissions.

The prevention is assumed to be mainly focused on the edible part of the food waste. In this study it is assumed that a decrease also in the amount of inedible food waste is possible, for example, if the prevention is a consequence of a smaller amount of food prepared or coffee made. The total prevention target of food waste in this study is allocated to the edible part and inedible part in proportion of

- Households: edible 70 %/ inedible 30 %
- Public and private sector: edible 90 %/ inedible 10 %
- Retail: total food waste 100 %.

The environmental impact analysis was limited to consider only the CO_2-eq emissions. CO_2-eq includes all greenhouse gas emissions multiplied with their global warming potential that is defined based on the effect that one unit of CO_2 has on global warming (McKeown & Gardner 2009). The analysis takes into account only the life cycle emissions of the wastes that are generated by the end user of a food product.

Economic impact assessment of food waste prevention was conducted from the end user's (waste generator's) point of view. It was determined that the possible cost savings consist of three different cost components (Table 15). Also, cost effects were considered as avoided effects at their full scale, which means that waste prevention actions do not cause any extra costs or lost revenues in retail, for example.

Table 14. The studied phases in environmental impact analysis of food waste prevention.

Phase	Households	Public sector	Retail	Private sector (retail excluded)
LC1: Early phase	From primary pro-duction to retail	From primary production to wholesale/retail	From primary producti-on to retail	From primary production to wholesale/retail
LC2: Usage phase	Transport and usage at home	Usage at public kitchens and canteens.		Usage at private restaurants etc.
LC3: Final phase	Waste manage-ment	Waste management	Waste management	Waste management

Table 15. The studied cost components in economic impact analysis of food waste prevention.

	Households	Public sector	Retail	Private sector (retail excluded)
Purchase cost	The average consumer prices	The average price per portion	The average whole-sale prices	The average wholesale prices
Usage cost	Transport, storing and cooking	Personnel, space and equipment	Personnel, space and equipment	Personnel, space and equipment
Waste management cost	Waste fee	Waste fee	Waste fee	Waste fee
Total	Sum of the previous	Sum of the previous	Sum of the previous	Sum of the previous

Households, the public sector and retail were considered more specifically. The private sector (other than retail, mainly including restaurants) was also included in the analysis with the assumption that some of the initial data related to the public sector can be generalised to apply to the private sector.

Average consumer prices per kg have been derived for different food product groups by applying the average consumer prices of over 100 food products and their weight indexes (Finland Statistics 2010a, 2011a). Purchaser prices for other sectors were assessed with the help of the consumer prices. It was assumed that the purchase price in the retail sector ison average 20–30 % lower than the consumer price[3]. The same price is applied in the rest of the private sector as well.

The average consumer prices of different food products in 2005 were defined.

Table 16 shows the average prices (€/kg) of different food products used in calculating economic impacts of waste prevention

It was assumed that the real consumer prices of meat and fish products rise 20% and other food products 10% in 2020 compared to the price level in 2005[4]. In the final economic impact analysis the price forecast in 2020 (expressed in year's 2005 value) were changed in year's 2010 value by using the money value coefficient 1.0988 (Finland Statistics 2011b) for ease the interpretation of the results.

The purchase costs of the public sector were calculated with the help of portions. An average portion size is 0.47 kg, which costs on average 0.71 € (Pelli 2011). With the assumed food price increase the cost will be 0.81 € per portion (1.72 €/kg, with VAT 1.92 €/kg) in 2020. This means that the food served in the public sector is prepared from cheaper-than-average ingredients, and/or the purchase of large amounts at once also lowers the average price.

Table 16. The average process (€/kg) of different food products used in economic impact of waste prevention calculations.

Product	Consumer prices in 2005 (inc. VAT)
Meat products	7.6
Dairy products	4.5
Grain products and bread	4.3
Vegetable products	2.8
Fish products	11.4
Fruit and berry products	2.5
Other products	6.7
Coffee (dry weight price)	5.6
Eggs	2.7

3 Estimates of the profits of the trade-sector vary a lot between different product groups. According to MTK (2011) the trade sector's share of the food's consumer price is typically approximately 30–45 %, but this includes also the share of wholesale.

4 On average this means 0.6-1.2 % annual growth in real prices. Therefore it is assumed that the real prices grow faster in the future than the national historical trend (2000–2010) would indicate (MMM 2010).

In the case of transports from retail to households only the cost of private cars was accounted for, as it was assumed that travel on public transport does not generate costs or that the costs would occur anyway. The costs of the usage phase in households were estimated from, for example, the energy used during shopping (based on average travel distances) and the energy consumed by kitchen appliances (Saarinen et al. 2011, National Passenger Traffic Survey 2004-2005, Korhonen 2006, Kodin energiaopas 2011, Laine 2011).

In the case of the public and private sector and retail, other cost components than purchase costs were calculated with the help of purchase costs when the total cost structure is known (Table 17).

The division of costs in the public sector represents the average shares observed in public food services. In the case of the private sector it has been assumed that the food purchases account for a higher share of the total costs due to the more expensive ingredients used in private food services compared to public food services. Otherwise the cost structure was assumed to be similar to that of public food services.

Cost data related to waste management in 2020 was obtained from the Helsinki Region Environmental Services Authority (HSY 2011) added with an assumption of 2% annual real price growth.

LC1: Early phase

In the case of food products the initial data related to the environmental impacts of the early life cycle phase is expressed per basic price[5] of a certain product chain using its value in 2005 (Table 18). These coefficients include Finnish domestic production and imports and all the life-cycle phases from primary production to the retail store (Virtanen et al. 2009). Therefore they also include the usage phase of the retail sector. To change the coefficients in Table 18 to mass-based coefficients, the basic prices per kg of food products were defined. Basic prices of the products can be estimated out of the consumer prices by taking away the trade and transport margins, taxes and adding the subsidies. Basic prices were estimated to be from 24 to 43 % smaller than consumer prices depending on the food product group.[6]

Table 17. Division of costs in food services and retail. Total costs consist of purchases (in this case food products), personnel costs and other costs, such as, space, equipment and waste management.

Cost parameter	Public sector (Kivistö 2011)	Retail (Sakki 2009)	Private sector (assumption based on Kivistö 2011)	Cost group
Product purchases	30%	75%	40%	Purchase
Personnel	50%	10%	43%	Usage
Other (incl. waste management)	20%	15%	17%	Usage and waste management

Table 18. CO_2-eq loadings per basic priced euro in the early phase of the life cycle in different product chains (Virtanen et al. 2009), coffee (Arvid Nordqvist 2007) and eggs (Saarinen et al. 2011).

Food chain	kg CO2 -eq/ €2005
Meat products	2.7
Dairy products	2.4
Grain products	1.8
Vegetable products	1.5
Fish products	1.0
Fruit & berry products	0.9
Other products	1.5
Coffee	2.8
Eggs	2.7

5 Basic price definition by OSF (Finland Statistics 2011a): “Basic price is a price concept in the national accounts. The basic price is the price receivable by the producers from the purchaser for a unit of a good or service produced as output, minus any tax payable on that unit as a consequence of its production or sale (i.e. taxes on products), plus any subsidy receivable on that unit as a consequence of its production or sale (i.e. subsidies on products). It excludes any transport charges invoiced separately by the producer. It includes any transport margins charged by the producer on the same invoice, even when they are included as a separate item on the invoice (Subsidies on products).”

6 Estimation is based on the statistic of basic priced and purchase priced supply of different food products in Finland in 2005 (Finland Statistics 2011c).

LC2: Usage phase

For food-related activities, the figure used for the annual per-capita emissions of Finnish households was 170 kg-CO_2-eq. The value includes the emissions of transportation, cold storage and cooking (Kauppinen et al. 2010).

Saarinen et al. (2011) have estimated that a family of four persons consumes 2343 kg of food per year at home (based on Viinisalo et al. 2008). Based on this, the average emissions of the usage phase in households amounts to 0.29 tCO_2-eq per ton of food consumed.

In the usage phase calculation relates to the public sector and other private sector were assumes that the emissions are caused by the energy consumption of the institutional kitchen. In the emissions calculations were presumed energy production profile that occurred in 2004 (Saarinen et al 2011). Based on the measurements conducted in the staff restaurant that uses Metos-equipment the energy consumption of food preparing, serving and cold storing is 0.63 kWh per kg of food in public sector (Jokinen 2012). In the private sector the energy consumption was assumed to be 25 % higher than in the public sector, because at least in some restaurants the benefit of scale is partly lost.

LC3: Waste management

Direct CO_2-eq emissions related to waste management are the sum of emissions from the transportation and treatment of waste and from the usage of the waste-originated end product. Indirect emissions are also caused by, for example, the production of the fuels used in transportation. In addition to direct and indirect CO_2-eq emissions, there are also emissions that are avoided due to the end products that are generated due to waste utilisation. Produced soil substitutes the peat uptake, etc., biomethane substitutes fossil fuels and energy substitutes average electricity and heat production.

Total waste management emissions (incl. source separated biowaste and biowaste that end up in mixed waste) in this study were the sum of direct and indirect emissions and avoided emissions, where the latter is expressed as negative emissions (Table 18). The emissions are area-specific and depend on the source separation rates, transportation distances and treatment methods. In this study the emissions per waste ton in the Helsinki region were calculated and generalised to apply to the other case regions (Table 19).

Table 19. Emissions related to waste management in the Helsinki region, kg CO2-eq / t

	Direct and indirect emissions	Avoided emissions	Total
Base case 2020	37	-96	-60
Prevention case 2020	39	-143	-104

2.2.2 Optimisation of biogas plant sizes, number and locations

A Geographical Information System (GIS) was used to identify suitable biogas plant site locations with particular respect to the spatial distribution of available biomass within the case regions. Suitable sites were defined as areas where the density of available biomass is high and a connection to the road network is available for the transportation of the raw material to a plant built within an acceptable distance from the consumer market (e.g. natural gas grid, filling stations). Furthermore, methods were developed to define collection areas for each candidate site and to calculate transportation costs and distances.

Site selection based on biogas potential

The first step in potential site selection was to identify those areas with high biomass density. For this purpose the biomass quantities generated annually in the case regions were computed by making use of statistical data. Then each biomass source was stored in a georeferenced GIS database and plotted onto a map with attributes indicating the amount and type of biomass and its biogas potential. After that, the Density application of ArcGIS Spatial Analyst was used to find areas with high concentrations of biomass and biogas potential. From the potential maps calculated in the above manner, locations were chosen which were inside those ‘hotspots’ of biogas potential, close to the road network and furthermore in the proximity of the existing natural gas grid in the Kymenlaakso region. Finally 22 potential sites for biogas plant construction in the Turku region, 13 in the Salo region and 14 in the Kymenlaakso region were identified.

Spatial optimisation/Minimising distances

For each of the potential sites, selected collection areas were derived using the Service Area application of ArcGIS Network Analyst. This application computes an area that encompasses all accessible streets that lie within a specified range (in this case the maximal transportation distance). The transportation distance over which biogas feedstock can be economically moved depends on its energy density and its transportation properties. In practice the transportation distances for raw materials vary from 10 km to 40 km (Dagnall et al., 2000; Palm, 2010). As it was found that at many of the selected sites, collection areas with a radius of 10 km would provide enough biomass to maintain a biogas plant with a production capacity > 3 MW, the transportation distance was set to 10 km. When collection areas overlapped, the Closest Facility application of ArcGIS Network Analyst was used to assign the raw material sources to the nearest site location by minimising the total (weighted) distances. Finally vehicle-specific transportation distances between the biomass sources and the potential site were calculated using the OD Cost Matrix application of ArcGIS Network Analyst. Based on this information, transportation costs could be estimated.

2.2.3 Environmental impact assessment of biogas production and use as a transport fuel

The sustainability of a fuel product depends on its environmental, economic and social impacts throughout its entire life cycle. The evaluation is based on the biomass amounts in each region and their usage as a raw material in the biogas production process. Different regions are not compared with each other; only the two case studies in the region are compared (Table 11).

The emission factors were calculated for every raw material used at the biogas plant using KCL-Eco LCA software version 4.1. The emission factors were calculated for both the base case and methane case, and the results are presented as kg CO_2-equivalent per ton of raw material. Then, the total emissions from the use of raw material at the biogas plant were calculated and compared with the situation when they are treated as in the base case. In the base case, the emissions from transportation in biowaste collection are included. The methane case includes emissions from not only raw material transportation, but also reject transportation and biomethane transportation in the Salo and Turku regions. In the base case the emissions from diesel and petrol use and manufacturing are taken into account. In the methane case, direct emissions from biomethane transportation use are calculated. For Turku, Salo and Kymenlaakso, the same emissions factors were used for all raw materials except biowaste due to differences in, biowaste treatment in each region. In the Helsinki region there are already three potential sources for biogas that are likely to use biogas for power and heat production in 2020 in the base case and thus in the Helsinki case region the comparison is based on the comparison of end use of biogas.

Biowaste

In the Salo, Turku and Kymenlaakso regions, there are differences in biowaste treatment in the base case (Table 13).

The efficiency of the waste incineration plant was assumed to be 20% for electricity and 60% for heat. The plant consumes 5% of the electricity it produces. Furthermore, it was assumed that only 25% (during 3 months) of the produced heat can be utilised. The assumptions used for gas boilers are presented in Table 20.

Table 20. Emissions and produced energy of gas boilers and gas engines (Møller et al. 2009; Börjesson & Berglund 2006).

		Gas boilers	Gas engines
Emissions to air			
CO_2	kg/ MWh_{biogas}	200	200
CH_4	kg/MWh_{biogas}	1.16	0.007
N_2O	kg/ MWh_{biogas}	0.0018	0.0018
Energy production			
Electricity	MWh/ MWh_{biogas}	-	0.32 – 0.4
Heat	MWh/ MWh_{biogas}	0.8	0.4

Manure

When emissions from the base and methane cases were compared, emissions from cowsheds, storage and fields were considered. Every manure source has specific emission factors (Grönroos et al. 2009; IPCC 2006). It was assumed that in the methane case, N_2O emissions are half and CH_4 emissions 60% smaller in the storage phase than in the base case. It was also assumed that the ammonium content of reject increases by 25% in the biogas production scenario (Luostarinen et al. 2011).

Field biomass

To simplify the calculations, some of the field biomass sources were grouped together depending on their properties. In the base case for 2020, the emission sources related to field biomass were the direct and indirect N_20 -emissions occurring during the decomposition of biomass. The calculations account for both the above- and below ground N -content of crops. The emission factors are based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). In the methane case, the cultivation phase of silage and the harvesting of silage, straw, tops and other agricultural waste and by-products were taken into account. Thus the emissions from fuel production and use of farm tractors were calculated. For the cultivation part, the assumptions shown in Tables 21 and 22 were used.

Table 21. Greenhouse gas emissions from farm tractors (VTT 2009).

Working machines, farm tractors	g/l
CO_2	2660
CH_4	0.15
N_2O	0.072

Table 22. Diesel consumption and emissions of different cultivation phases (Mikkola & Ahokas, 2009; Sokerijuurikkaan tutkimuskeskus 2010-2011).

	CO_2	CH_4	N_2O
	g/ha	g/ha	g/ha
Tops	39900	2.25	1.08
Straw	17290	0.98	0.47
Silage	182835	10.31	4.95

Biomass transportation

The greenhouse gas (GHG) emissions of a heavy (15 t) delivery lorry in urban driving (VTT 2009) were used for calculating the emissions from biomass transportation to a biogas plant. It was assumed that the same vehicle delivers the digested biomass for use as soil amendment, and therefore none of the return trips are driven with an empty load. Table 23 presents the emission factors of the lorry.

Biogas production

Raw materials are transported to the biogas plant, where they are pre-treated and digested. The studied biogas plant is a large-scale mesophilic biogas plant using single-stage digestion technology. After digestion the sludge is pumped into a nonheated covered storage tank where some residual methane is produced and recovered. Subsequently the digested sludge is stored uncovered, and then it is transported and spread into the fields during summertime. The produced biogas is pumped into the upgrading plant, distributed and used as transport fuel. The used data on energy values at the biogas plant is based on average literature values (Table 24).

Biogas as a transport fuel

In the biomethane case, the biogas is purified. The purification process was assumed to be an amine-based chemical adsorption process, which uses electricity from the grid. The heat needed in the process is produced by a woodchip boiler. It was assumed that the process recovers more than 99% of the methane from the raw biogas, while losses are less than 1% (even 0.1%). The methane content of raw biogas was assumed to be 60%. The product gas contains more than 99% methane and is available for use as vehicle fuel or to be fed into the natural gas grid. In order to deliver biomethane to the transportation sector the gas is compressed to the natural gas grid's pressure and to refuelling pressure. Electricity used in compression is taken from the grid. The heat from the upgrading process can be recovered and used in the biogas reactor to pre-heat the substrate. In this study a 70% heat recovery rate is used (Table 25) (Läckeby Water Group 2009).

Table 23. The emission data of delivery lorry (VTT 2009).

	CO_2 [g/km]	CH_4 [g/km]	N_2O [g/km]
EURO 5 Delivery lorry (15 t) (urban drive) 50% load	613	0.024	0.033

Table 24. Data used for energy use at the biogas plant.

Biogas plant:	MJ/t, raw material	Reference
Heat consumption (reactor heating)	230	e.g. Berglund & Börjesson 2003, 2006 and Tuomisto & Helenius 2008
Electricity consumption (pumping & mixing)	100	e.g. Berglund & Börjesson 2003, 2006 and Tuomisto & Helenius 2008
Digestate:	MJ/t, digestate	
Loading (from storage)	2.74	Smyth et al. 2009

Table 25. Energy use for biogas upgrading process.

	kWh / Nm^3 raw gas
Electricity	0.1
Heat use	0.55
Heat recovery	70%

The natural gas grid can be used for delivering biomethane to filling stations in the Kymenlaakso and Helsinki regions. In the Turku and Salo regions, it was assumed that the purified and pressurised biomethane was transported with tanker-trucks, and these emissions were included in the calculation.

When the biomethane is used as a transport fuel, it replaces conventional fuels. Therefore, in the biomethane scenario, the emission credits from the decrease in fossil fuel production are considered. The direct emissions of biomethane vehicles were accounted (Table 26).

In the Helsinki region, it is assumed that biomethane is used in biomethane busses and thus receives emissions reduction credits from diesel production. In the Turku, Salo and Kymenlaakso regions, it was assumed that biomethane replaces both diesel and petrol and that it is used in different car types, with all local busses and waste trucks and 10% of other heavy trucks using biomethane. The rest of the produced biomethane was assumed to be consumed by vans and passenger cars (Table 27).

Emission data of busses were used for all other car types, except for passenger cars. For petrol and diesel production, the figures used for emissions were 115.8 and 87.5 kg/kWh CO2-eq, respectively.

Based on the information on the biomethane consumption of different car types, the kilometres driven with 1 MWh biomethane were calculated, along with how much petrol and diesel would be needed to drive the same distance. Then the emissions caused by the usage of petrol and diesel vehicles and also the fuel production emissions were calculated. Thus, the emission factors for diesel and petrol cars per MWh biomethane were obtained (Table 28).

Table 26. Bus GHG emissions used (VTT 2009)

	Consumption [kWh/km]	CO_2 [g/km]	CH_4 [g/km]	N_2O [g/km]
EURO 5 diesel bus (urban drive)	4.2	1105	0.033	0.030
EURO 5 biomethane bus (urban drive)	5.9	-	1.0	0.032
EURO 5 Passenger car, diesel(1.7 passenger, urban drive 35%)	0.63	165	0.0006	0.0053
EURO 5 Passenger car, petrol (1.7 passenger, urban drive 35%)	0.62	164	0.001	0.0021
EURO 5 Passenger car, biomethane (1.7 passenger, urban drive 35%)	0.6	-	0.2	0.001

Table 27. The share of biomethane used by different vehicle types.

	Turku and Salo	Kymenlaakso	Fuel replaced
Busses	3%	1%	100% diesel
Waste trucks	<1%	<1%	100% diesel
Heavy trucks	6%	5%	100% diesel
Vans and delivery cars	9%	9%	100% diesel
Passenger cars	81%	83%	50% diesel, 50% petrol

Table 28. The emission factors for biomethane use in each region.

	kg CO_2/MWh biomethane	kg CH_4/MWh biomethane	kg N_2O/MWh biomethane	kg CO_2-eq./MWh biomethane
Biomethane car emissions				
Turku and Salo & Kymenlaakso	0	0.3	0.002	8.3
Production emissions of petrol and diesel				
Turku and Salo	43.6	0.15	0.0008	47.63
Kymenlaakso	43.4	0.16	0.0007	47.52
Petrol and diesel car emissions				
Turku ja Salo	252.2	0.0022	0.0058	253.93
Kymenlaakso	258.6	0.0018	0.0082	261.05
Total Turku and Salo	295.8	0.150	0.007	301.6
Total Kymenlaakso	302.0	0.16	0.009	308.6

Digestate as a soil amendment

In the methane case, it is assumed that the amount of digested sludge produced is equal to the amount of raw materials used by the biogas plant. In reality, the digested sludge amount varies depending on the amount of water used at the plant. It is also assumed that no water separation occurs after digestion. The digested sludge is used as soil amendment in the fields, which decreases the need for mineral fertilisers. The examination is made for N fertiliser, and for this, the soluble N content of total N is needed.

In the base case manure is also used as soil amendment and thus the N content of raw manure after atmospheric deposition and leaching/runoff is calculated. In the methane case the N content is calculated for all materials separately when they are digested. The soluble N amount of each raw material is the amount of mineral N fertiliser avoided. It is assumed that the digested sludge is transported during the return trip of raw material transportation.

2.2.4 Economic impact assessment of biogas production and use

The base case and methane case were compared by appraising the costs and benefits of market value of the end products compared to the cost of production and employment effects.

The focus was on regional effects and no stance was taken on who the actor is in the market. If waste treatment is outsourced and the benefits are spread across the region, positive effects are not taken into account. For instance, in the base case, all source-separated biowaste from the Turku and Salo regions is treated in the Forssa region. Then income from energy production and the employment effects of waste treatment are left across the examination, but the negative effects of gate fees and transportation are allocated to the case regions.

In the economic impact assessment, the preconditions for economical biomethane production were defined first. To that end, the cost of biomethane production was determined for each biomethane production plant.Then the inputs and outputs of biomethane production were compared to the base case.

2.2.4.1 Base-case

The cost of waste treatment facilities were mainly based on a report by the Ministry on the Environment (Ympäristöministeriö 2010) (Table 29). Original research is carried out under the POLKU-project[7].

Table 29. Costs of waste treatment facilities

Wastetreatment facility	Capacity	Investment	Cost of production of operation		
			Capital	Running	Total
	t/a	Mill. €	€/t	€/t	€/t
Mixed waste incineration	139 000	78	45	27	72
Tunnel composting	56 000	23	40	40	80
Anaerobic digestion	75 000	11	12	15	27

When waste treatment is outsourced across the region, average gate fees are used as the cost level for waste treatment (This is because gate fees may change within the time span examined and vary regionally according to the competitive situation). The average gate fees are 98 €/t for biowaste treated with mixed waste at incineration and 76 €/t for source-separated biowaste (Tietoa jätehuollosta 2009).

In the base case biowastes are converted to energy at CHP units regardless of whether the treatment technology was incineration, biogas production or landfill gas recovery. In incineration, a ton of biowaste produces 0.15183 MWh electricity and 0.53 MWh heat. One third of the produced heat is expected to be utilised. Costs of CHP are included in the costs per ton of biowaste (€/t).

The cost of biogas CHP depends on the investment costs and running costs, including monitoring, management and maintenance. Investment CHP varies according to production scale (Fig 4). Investment data is derived from KTBL's biogas production cost model (KTBL-Biogasrechner 2011). Specific investment per power output (€/kWel) declines as the power output of a CHP unit grows, being e.g. 620 €/kWel at 1000 kWel power level and 540 €/kWel at 2000 kWel level. Running costs of CHP results vary between 0.0075 – 0.015 €/kWh_e (Aebiom 2009; Simader et al. 2006). The same figures are also used for appraising the CHP costs of landfill gases and biogas from sludge.

Appraisals of employment effects are based on multiple environmental impact appraisal reports and existing domestic plants. For the building phase, only the need to build new capacity is taken into account.

Continuous employment directly at incineration plants is 37 person-years per 100 000 tons of incinerated waste. Employment in biogas production is relatively low due to the high automation of the processes. For example, according to Hagström et al. (2005), the average employment provided by biogas production at wastewater treatment

7 POLKU-project - Polttokelpoisten jätteiden hyödyntäminen ympäristö- ja kustannusvaikutusten kannalta, 2008.

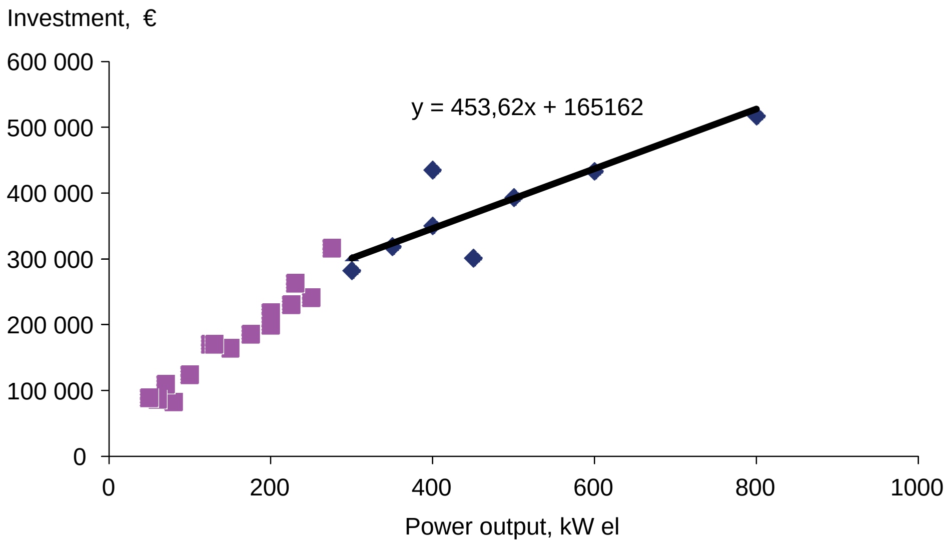

Figure 4. Investment cost of CHP

plants in Finland amounts to 0.2 person-years, at landfill 0.3 person-years, at biowaste treatment plants 3 person-years and at farms 0.05 person-years per biogas plant. Here, the expected continuous employment effect is 5 person-years per 100 000 tons of treated biowaste. It is noteworthy that the management of biowaste treatment may require far more employees, but such employees are not included in the employment calculations.

Employment in the building phase results mainly from land construction work, concrete works, engineering and transport. It is notable that expressed person-years allocate to a few years in the building phase, and especially engineering work may not be allocated to the region. The expected employment effect of building an incineration plant is 25 – 30 person-years and that of building a biogas plant about 40 – 50 person-years per 100 000 tons of annual treatment capacity.

According to the Ministry of the Environment (Ympäristöministeriö 2010) the average cost of biowaste transport is 76 €/t and that of sludge 4 €/t. These figures are however just rough appraisals and the costs vary according to transport distance and the organisation of the transportation work, that is, whether the service is outsourced or self-organised. According to HSY, the cost of biowaste transport is 86 €/t and the average transport distance is 13 km/t.

With sludge there is not much difference in the distance accrual between the methane and base cases. The average transport cost is calculated as 6 €/t. However, biowaste is treated at a number of different plants in the methane case and the average distance accrual declines to 1/10. This results in a lower transport cost, estimated at 9 €/t.

2.2.4.2 Methane case

Biomethane production is an investment-intensive branch of industry, which means that the expected interest rate and depreciation time have an important role in determining production costs[8]. Part payments are calculated using the annuity method with a 6.5% real interest rate. The interest rate is conservative, but justified by the current crisis in the financing market, which may raise the cost of loan financing. If not, it overestimates the capital costs and gives a slight profit margin to production.

The economic lifetime[9] of industrial energy investments is usually long (30 years), but since technology in the biofuel industry is developing rapidly, there are good grounds to shorten the economic lifetime of the plants to 15 years. As components (e.g. pumps, compressors and motors) are expected to wear out before that, the lifetime is determined according to technical working hours. Investment aid is expected to be 30% in the case of components directly linked to biogas and biomethane production.

8 Herein, production cost means cost price, which does not include either profit or profit tax. It is the cash flow needed to pay yearly operating costs and fixed costs during the economic lifetime of a plant.

9 Economic lifetime is the time span during which the used technology is expected to be competitive in the market.

Investment and operating costs in the year 2020 are calculated in line with the real price level in 2010, which excludes the effect of inflation. Table 30 presents the price expectations of energy products used in the production cost calculations. The prices include production-related taxes, excluding value added tax (VAT).

Table 30. Prices of energy products in 2010 and forecast for 2020 at year 2010 real price level.

		2010		2020	
		Producer	Market	Producer	Market
		price	price	price	Price
Electricity					
Nord pool spot price	€/MWh	41.4[a]	87.3[b]	45[c]	95
Feed-in tariff for biogas, basic level	€/MWh	83.5[d]	87.3	83.5	95
Feed-in tariff for biogas, added heat bonus	€/MWh	133.5[d]	87.3	133.5	95
Heat					
District heating	€/MWh	20	43.3[e]	25	45[f]
Power plant woodchip boiler	€/MWh	35[g]	-	37	-
Fuels					
Diesel	€/MWh	-	95[h]	-	126[f]
Motor fuel oil	€/MWh	-	64[h]	-	89[f]
Biomethane for fuel	€/MWh	30[k]	83[l]	40[k]	100
Natural gas	€/MWh	18.2[f]	31.3[i]	29[f]	49[f]
Wood -chips	€/MWh	-	18[m]	-	18.8[f]
			17.8		17

A Average Nord Pool Spot price 2010

B Supply price for electrcity consumer type 3x35A. Energiamarkkinanvirasto, Energy Market Authority

C VTT forecasts with Nordic times model, based on IEA's New Policies energy products price forecast

D TEM, Ministry of Employment and the Economy

E Weighted average of distric heating prices, consumer type 450 MWh/a. Energiateollisuus, Kaukolämmön hinnat 2010.

F Change based on IEA's New Policies energy products price forecast

g Production cost calculations of the W-Fuel project

h Finnish Pertoleum Federation

i Consumer type T2, 8.3 MW, 6000h. Energiamarkkinavirasto, Energy Market Authority

k Expected selling price to the natural gas grid

l Delivery price at fuel station

m Price monitor of woody fuels, Pöyry

2.2.4.3 Raw materials

Biowaste and sludge

From the economic point of view the most beneficial biomasses are biowastes, which also have a relatively high methane yield. The second best category comprises biosludges; as they mostly contain water, they do not contribute much net energy, but their income effect through gate fees can be notable. Obviously the handling of these materials is also more expensive due to pre-handling needs (crushing and hygienisation) and possible difficulties in finding a reasonable end usage for the digestate.

All digestate was expected to be allocated for field spreading to enhance effective nutrient recycling. Nutrients from these sources thus originate from agriculture and are from outside of a single biogas plant's farming system. This means that the nutrient input can also be calculated as an economic value but since finding spreading field area for digestate, originated from biowaste and sludge, is more like a challenge than economic opportunity. Value of nutrients was excluded from calculus.

Manure

An important economic benefit comes from manure storages at farms. They may remarkably reduce the need to invest in liquid digestate storages. Another factor affecting the need for liquid storage capacity is that the amount of liquid digestate can be reduced by mechanical drying (slinger). If this method is used, the liquid storage need of digested manure reduces to 2/3, and extra space can be filled with liquid digestate originating from other sources. Taking into account that these materials are often high in dry matter content, it is possible that there is no need for any extra liquid digestate storage capacity.

Field biomasses

The cost of using field biomasses is accounted for by harvest and transport. Also the cost of transporting and spreading digestate to fields is paid by the biogas plants, but the cost is generally allocated to the handling of digestate. The field biomasses themselves were expected to be free of charge.

2.2.4.4 Farming systems

Farming of silage was expected to be carried out on a large scale by contractors with high-performance harvest machinery. The basic concept is that the cost of harvest, transport and fertilising with digestate is paid by the biogas plants. It is the role of farmers to seed and plough the field after the grass farming period in crop rotation. Income for farmers comes from agricultural support, which covers the marginal cost of machinery and work, including the cost of field capital, providing a relatively better profit margin compared to cereal farming.

Table 31 presents the costs of silage and cereal farming. The expected yearly harvest area with the machinery chain is 1 000 hectares and the average transport distance is 6 km. The profit of the contractor is 10% of the total cost. Silage harvests are conducted twice during the growing season, yielding a total crop of 7.5 t TS/ha. The crop of cereal straw is 3 t TS/ha. Transport driving speed is 30 km/h and salaries are 12 €/h plus 58% social costs.

By-products were expected to be free of charge. Farmers are motivated to give out by-products because this enables them to get nutrients free of charge and eliminate fieldwork that harms vegetable tops and straw. This is especially important in the direct sowing of cereals.

Table 32 presents the regional net value of end products per hectare depending on crop usage, that is, whether the crop is allocated to biomethane production or exported as surplus cereal production. Harvested straw is considered to be an additional by-product of cereal farming. Thus, none of the agricultural support or costs of cereal production are allocated to straw.

Liquid digestate was assumed to be transported with 32 m^3 semi-trailer combinations, with intermediate storing in freight containers. The digestate is spread with a 17 m^3 tractor-pulled manure spreading wagon. Liquid digestate is spread twice a year onto grass fields at the beginning of the crop-growing season. Because the N/P-ratio of liquid digestate is close to the requirements of the plants, no extra chemical fertilising is expected to be necessary. Solid digestate is allocated before sowing to the cereal plots within the crop rotation.

Biomethane production

Biomethane production is an investment-intensive industry. Thus, economies of scale can be clearly seen in biomethane production. The specific investment per power output (million €/MW) decreases rapidly until 2 – 3 MW power output, but stabilises after that (Figure 5). This gives a basis for scaling production to the most economical level. Investment data on biogas production is largely based on KTBL's biogas production cost model (KTBL-Biogasrechner 2011). Upgrading investments are derived from research made by Urban et al. (2008).

Table 31. Cost of silage and cereal production and harvesting straw

SILAGE PRODUCTION					CEREAL PRODUCTION				
	Unit	Unit price	Amount/ha	€/ha		Unit	Unit price	Amount/ ha	€/ha
Income					Income				
Agricultural support	ha	540	1	540	Agricultural support	ha	540	1	540
Crop price	t	0	22	0	Crop price	t	180	4	720
Total				540	Total				1 260
Cost for farmer					Cost for farmer				
Seed	kg	-2.8	9	-25	Seed	kg	-0	205	-62
Pesticides	ha	-24.0	1	-24	Fertilising	kg	-1	350	-175
Fuel	dm³	-0.9	10	-9	Liming	t	-44	0	-11
Salary	h	-19.0	3	-57	Pesticides	ha	-26	1	-26
Machinery	h	-30.0	1.5	-45	Fuel	dm3	-0.9	63	-57
Field	ha	-300	1	-300	Electricity	kW	-0.12	41	-5
				-460	Transport freight	t	-20	4	-80
					Salary	h	-19	7	-138
Farmers' profit (+) / loss (-)	€/ha			80	Machinery	ha	-380	1	-380
Income, work included	€/ha			137	Dryer building	ha	-100	1	-100
´-"-	€/h			46	Field	ha	-300	1	-300
Farmers' work	h/ha			3					-1 334
					Farmers' profit (+) / loss (-)	€/ha			-74
Cost for biogasplant					Income, work inclu-ded	€/ha			65
Silage harvest by cont-ractor	Unit	Unit price	Amount/ha	€/ha	´-"-	€/h			8.9
Silo plastic	kg	-3.0	6.6	-20	Farmers work	h/ha			7
Fuel	dm³	-0.9	62	-56					
Salary	h	-19.0	3.4	-64	HARVESTING STRAW				
Machinery	ha	-200.0	1	-200					
				-340	Cost for biogas plant	Unit	Unit price	Amount/ ha	€/ha
Digestate transport and spreading by contractor					Harvest and transport by contractor				
Fuel	dm3	-0.9	22	-20	Fuel	dm³	-0.9	23	-21
Salary	h	-19.0	1.2	-23	Salary	h	-19	1.8	-34
Machinery	ha	-70.0	1	-70	Machinery	ha	-74	1	-74
				-113					-129
Energy yield, biogas	MWh th/ ha			22.3	Energy yield, biogas	MWh th/ ha			6.3
Cost of silage	€/ha			-453	Cost of straw	€/ha			-129
-""-	€/t FM			-21	-""-	€/t FM			-34
-""-	€t TS			-60	-""-	€t TS			-43
-""-	€/MWh th			-20	-""-	€/MWh th			-20
Contractor work	h/ha			4.6	Contractor work	h/ha			1.8

Table 32. Regional net value accrual (€/ha) of the end products in the base and methane cases.

METHANE CASE			BASE CASE		
Silage production			Cereal production		
Value of the production			Value of the production		
Selling price of biomethane	€/MWh	100	Selling price of cereal	€/t	180
Crop level	MWh/ha	22.3	Crop level	t/ha	4.0
End value of the crop	€/ha	2 230	End value of the crop	€/ha	720
Agricultural support	€/ha	540	Agricultural support	€/ha	540
		2 770			1 260
Cost of production					
Silage	€/ha	-913	Cost of producton	€/ha	-1 334
Biogas production	€/ha	-669			
Upgrading	€/ha	-335	Net value of production	€/ha	-74
Biomethane delivery	€/ha	-312			
		-2 228			
Net value of production	€/ha	542			
Harvesting straw					
Value of the production					
Price of biomethane	€/MWh	100			
Crop level	MWh/ha	6.3			
End value of the crop	€/ha	630			
Agricultural support	€/ha	-			
		630			
Cost of operation					
Harvesting	€/ha	-129			
Biogas production	€/ha	-189			
Upgrading	€/ha	-95			
Biomethane delivery	€/ha	-88			
		-500			
Net value of production	€/ha	130			

The investment calculation of biogas and biomethane production includes multiple process units. The need for different process units depends on the production concept, where the most important factor is the composition of the input biomass. The production units incorporated in the calculations are presented in Table 33.

The running costs of biomethane production vary mostly according to the economic status of input biomasses. Electricity is used in various phases of the processes. The phase that consumes the most power is upgrading. Diesel oil is used in feeding solid biomass to the reactors by means of wheel loaders; also, if solid digestate is composted, diesel is used for turning the compost with an excavator. Insurance is expected to be 1.2% of the investment. Labour costs are typically around 10% of the running costs. Yearly costs and incomes are the main determinants of the production costs of biomethane (Table 34).

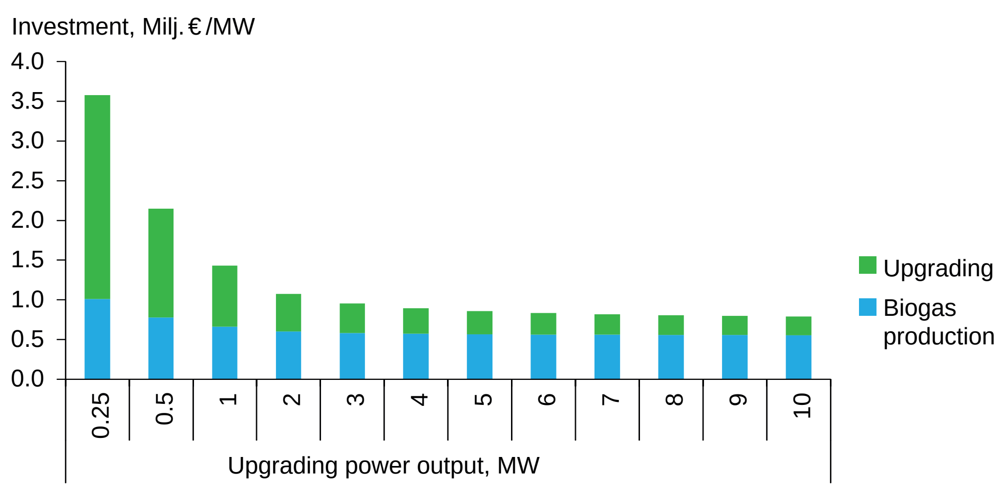

Figure 5. Specific investment per power output (milllion €/MW).

Table 33. Process units of biomethane production investments

Biogas production	Biomethane production
Feeding units, sludge and solid biomass	Upgrading unit
Hygienisation unit	Gas compressor
Reactors	Heating unit, woodchip boiler
Reject tanks	
Torch	Common investments
Slinger	Plant area
Wheel loader for solid biomass feeding	Project management
Excavator for compost turning	Starting costs
Bunker silos for solid biomas	
Liquid reject storages	
Composting field construction	

Table 34. Yearly cost and incomes of biomethane production.

YEARLY COSTS	YEARLY INCOME
Running costs	Gate fees
Biomass	Biomethane sold
Electricity	
Diesel oil	
Lubricant oil	
Heat fuel, woodchips	
Service and maintenance	
Insurance	
Labour	
Interest on floating capital	
Investment costs	
Interest on borrowed capital	
Depreciation	

Biomethane delivery

Biomethane can be delivered through the natural gas grid or by wheels to refuelling stations. The best option depends on the transport distance. A steel container is the cheapest option for transport distances less than 35 - 40 km; for longer distances, a carbon fibre container is the more economical choice (Fig. 6). The investment cost of a steel container is expected to be 90 000 € and that of a carbon fibre container 250 000 €.

Building a gas pipe is expensive and becomes more profitable than road transport only at short distances or with high gas volumes. Important measures also include the expected depreciation time and the used interest rate (Fig. 7). In addition, the investment depends on the length of the natural gas pipe, and the terrain also affects the appraised cost. In sparsely populated areas the average cost of a pipe is lower than in urban areas where street and railroad intersections are needed. According to the Energy Market Authority (Energiamarkkinavirasto 2010) the specific investment required per metre of pipe varies from 67 to 205 euros (€/m). However, these figures do not include all the costs. According to Kuningas & Kärki (2011), the appraised total investment level varies at short distances (<10km) from 500 €/m to 600 €/m and at longer distances between 350 – 450 €/m.

The investment required to connect a gas pipe to the existing gas grid is appraised to be 100 000 €. The investment in a natural gas analysing system, which is needed to measure the amount of biomethane injected into the grid, is appraised to be 50 000 €.

There are 16 refuelling stations for natural gas in Finland (Gasum 2012). These can also deliver biomethane. However, the capacity of the refuelling stations is limited and they are located along the natural gas grid only in the HSY and Kymenlaakso regions. Thus new refuelling stations are needed. If a new station is sited along the gas grid, the grid itself works as a gas storage facility. In cases where biomethane is transported by road the gas is stored in the gas transport containers. In the basic concept there are three containers per biomethane production unit. One is refuelled at the upgrading unit, another is on wheels and the third one is at the refuelling station. The cost of investments in refuelling stations and compressors, which are needed to increase the gas pressure, depends on the refuelling capacity of the refuelling stations (Fig. 8).

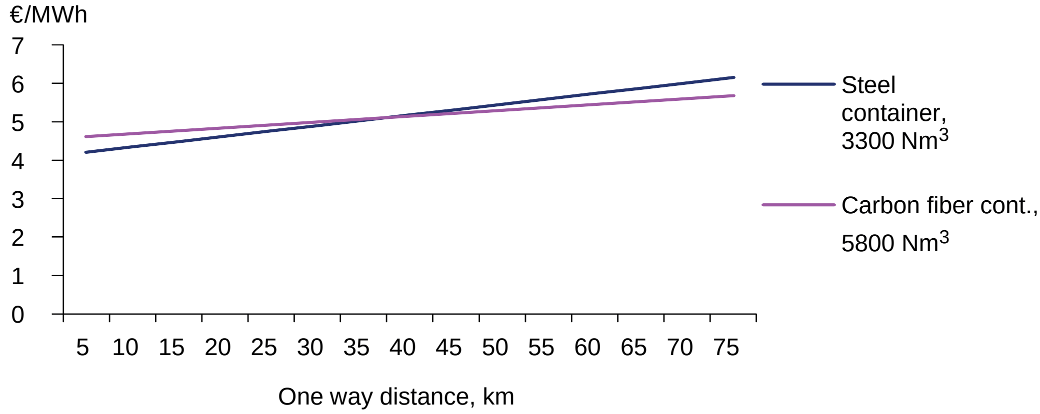

Figure 6. Cost of biomethane transport by wheels, €/MWh

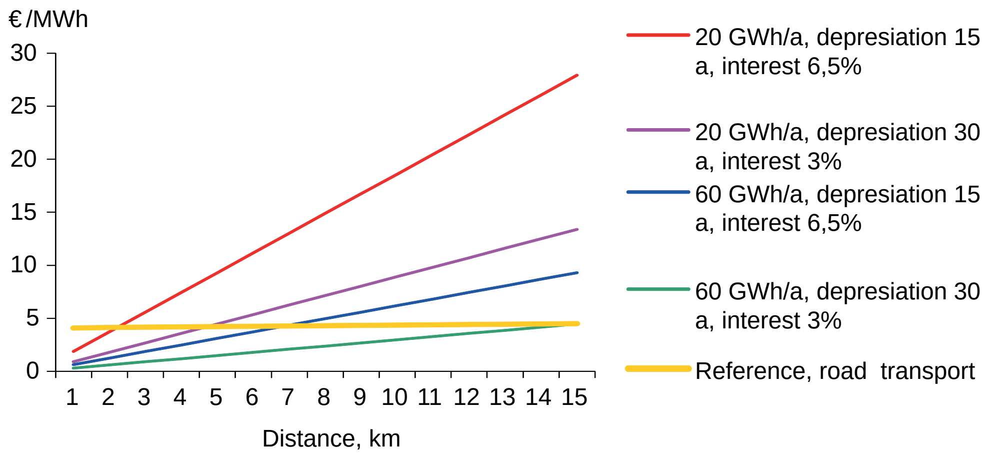

Figure 7. Cost of biomethane transport by gas pipe compared to road transport, €/MWh.

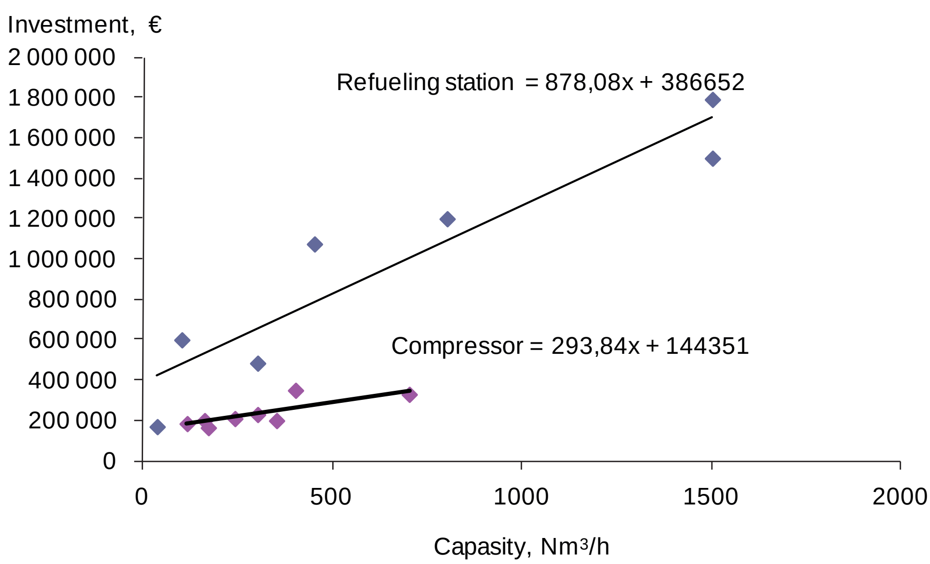

Figure 8. Investment cost of refueling stations (Biogasmax 2010, Ahonen 2010) and compressors at the stations (Biogasmax 2010, Uusi-Penttilä 2004).

Running costs of refuelling are divided into the costs of service and electricity. Service cost is appraised to be 0.5% of the investment in refuelling stations and 2% of the investment in gas compressors. To calculate the energy consumption of a compressor, the end temperature of the compressed gas is calculated by using an adiabatic compression equation:

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{R}{c_p \eta}} \qquad \text{(E1)}$$

Where T = gas temperature, p = gas pressure, R = gas constant (8.314 J/molK), c_p = specific heat capacity, η = polytrophic efficiency (White 2003).

The needed power of the compressor is calculated by using the equation:

$$P = q_m c_p \Delta T \quad \text{(E2)}$$

Where P = power, q_m = mass flow (White 2003).

When gas is pressurised from 1 bar to 54 bar (gas grid pressure) electricity consumption is 0.143 kWh/m³ and when the pressure is pumped up from 54 bar to 250 bar, electricity consumption is 0.045 kWh/m³. The electricity consumption of the refuelling station is expected to be 0.1 kWh/Nm³.

According to the biogas production model created in the W-Fuel project, the specific production cost of biogas varies from 30 to 40 €/MWh of biomethane when including the transport cost of biomass and reject as well as reject field spreading, but excluding the cost/income of biomass. The specific cost of upgrading varies from 13 to 17 €/MWh of biomethane. The cost of biomethane transport varies between 0-8 €/MWh depending on the transport distance and mode of transport. The average refuelling cost is 9 €/MWh th at 55% usage level of refuelling capacity. These figures are in line with the findings of Jönsson (2009), who reported that the total upgrading cost was 11-25 €/MWh th biomethane injected into the gas grid.

2.2.5 Regional impact assessment

The regional impact assessment includes changes in waste material treatments, economic effect on agriculture and employment effects.

Biowaste, sludge and landfill gas are the most economical sources of biomethane. All the potential is used for production regardless of the expected consumption growth paths. Thus, impact assessment involves comparing CHP production (base case) and biomethane production (methane case). The economic effect on agriculture is assessed in terms of income to farmers and contractors or as net value of production. The effect on agriculture results from changes in crop production and transport needs. Employment effects are directional, appraised with general employment factors. Person-years are defined as 1820 hours per year. It is notable that the building phase of the plants yields high employment figures. However, this effect amounts to just a few years and might not be allocated in full to the region. Total employment represents the employment effect of production. It is the sum of continuous and building phase employment, where employment in the building phase is spread out over the expected 15-year economic lifetime of the plants.

3 Results

3.1 Waste prevention

3.1.1 Prevented waste amounts

The biowaste amount and the food waste amount were anticipated to grow in the base case for the year 2020 by 1–11% on average from the year 2009 amounts in different case regions, whereas in the prevention case for the year 2020 they were forecast to decrease by 30% compared to the level in 2009. The difference between the total food waste amounts in the base case and prevention case in 2020 is approximately 90 000 t in the case regions, which equals from 33 to 57 kg per capita, being the lowest in Kymenlaakso and the highest in the Helsinki region (Table 35). The household sector accounts for almost half of the prevention target, as the food waste volume per capita in the year 2020 is 25 kg lower in the prevention case than in the base case. The other half of the total prevention target is achieved in public and private services.

The Helsinki region accounts for 75% of the total prevention target due to the fact that the Helsinki region is the most populated region and food waste generation per capita is higher in this region than in other regions.

Most of the prevention target is obtained by reducing the amount of edible food waste, because it was assumed that it is easier to avoid this type of waste. Because the prevention target was not set proportionally for edible and inedible waste, the composition of food waste that is still generated in the prevention case differs from the composition of food waste in 2009 and the base case 2020.

Table 35. The difference in the amount of food waste between the base and prevention cases in different sectors and case regions in 2020, tons and kg/capita.

	Households		Public sector		Retail		Private sector other than retail		Total		
	t	kg/ capita	t	kg/ capita	t	kg/ capita	t	kg/ capita	t	%	kg/ capita
Turku region											
Edible	4590	13	1273	3,7			2063	6,0			
Inedible	2626	8	193	0,6			347	1,0			
Total	7216	21	1470	4,3	2582	7,5	2410	7,0	13677	15 %	40
Salo region											
Edible	1087	13	261	3,2			305	3,8			
Inedible	655	8	42	0,5			54	0,7			
Total	1742	21	302	3,7	645	7,8	359	4,4	3048	3 %	38
Helsinki region											
Edible	19299	16	7397	6,3			7578	6,4			
Inedible	13083	11	1072	0,9			1144	1,0			
Total	32382	27	8469	7,2	18030	15,3	8722	7,4	67603	75 %	57
Kymenlaakso											
Edible	2365	13	503	2,8			773	4,2			
Inedible	954	5	71	0,4			123	0,7			
Total	3318	18	574	3,2	1238	6,8	896	4,9	6026	7 %	33
Edible	27341	15	9434	5,3			10719	6,0			
Inedible	17318	10	1378	0,8			1668	0,9			
Total	44658	25	10815	6,1	22495	12,6	12387	6,9	90354	100 %	51
Share	49 %		12 %		25 %		14 %		100 %		

3.1.2 Environmental impact assessment of food waste prevention

The GHG emissions from food waste in households and public and private services were calculated for the base and prevention cases for the year 2020. The GHG emission savings in the prevention case in the Helsinki, Turku, Salo and Kymenlaakso regions range from 14 000 to 310 000 CO_2-eq (Table 36). Altogether the prevention case results in savings of about 415 000 tCO_2-eq (Fig 9).

Over 40 % of the emissions are saved in households, about 30% in retail, 16% in the private sector and 12% in the public sector (Table 37).

Figure l0 shows the emissions divided into the early phase, usage phase and waste management phase in the base and prevention cases.

Table 36. Emissions from total food waste amounts in the case regions in year the 2020 in the base and prevention cases and total emission savings (all sectors) tCO_2-eq

	Helsinki region	Turku region	Salo region	Kymenlaakso	Total
Base case	700 000	140 000	30 500	71 000	940 000
Prevention case	390 000	78 000	17 000	42 500	530 000
Total emission savings	310 000	63 000	14 000	29 000	415 000

Table 37. Emissions in the compared sectors (all regions) tCO_2-eq.

		Households	Public sector	Retail	Private sector	Total
Base case 2020	tCO_2-eq	349490	128131	317450	146239	941310
	Share	37 %	14 %	34 %	16 %	100%
Prevention case 2020	tCO_2-eq	169847	76675	197980	81910	526412
	Share	32 %	15 %	38 %	16 %	100 %
Total emission savings due food waste prevention	tCO_2-eq	179643	51456	119470	64329	414898
	Share	43 %	12 %	29 %	16 %	100 %

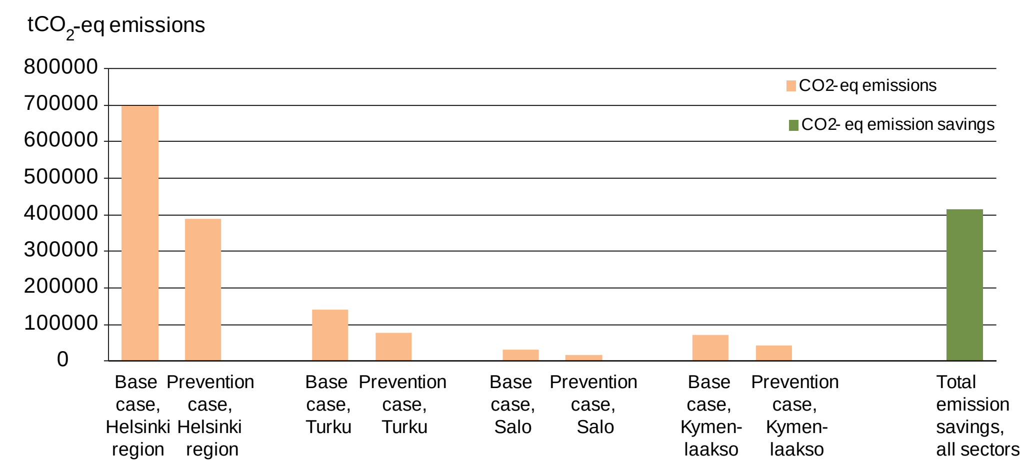

Figure 9. CO_2-eq-emissions in different cases and case regions and total emission savings, t.

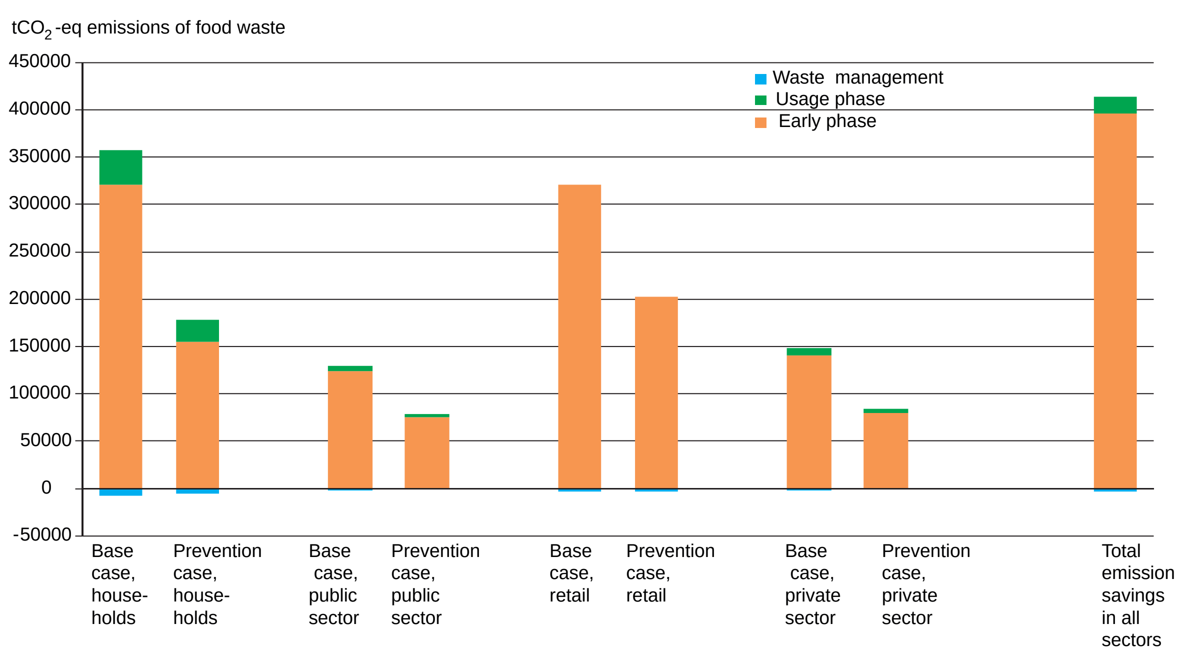

Figure l0. Emissions of food waste divided into different life cycle phases in different sectors and the base and prevention cases and the total emission savings in 2020. The early phase of retail includes also the usage phase.

3.1.3 Economic impact assessment of food waste prevention

The economic impacts of food waste prevention were calculated by comparing the cost of the total amounts of food in the base and prevention cases. Taking into account all sectors in all the case regions, food waste prevention will save on average nearly 300 €/capita in 2020 (Table 38). Mainly due to the higher food waste amounts per capita, the cost savings per capita in the Helsinki region are 38–66% higher than in other regions, but the area-specific food waste developments in the base case also cause regional variation in the results. These area-specific amounts also affect the cost savings expressed per ton of food waste, where the average results varied from 5840 to 6140 € regionally.

In the prevention case, the waste generators in households, retail and both public and private food services will save almost 400 M€ in the Helsinki region, 84 M€ in Turku, 18 M€ in Salo and 37 M€ in Kymenlaakso. Altogether this equals over 0.5 billion €. 40% of the total cost savings in all case regions are direct savings for consumers, and the rest are gained in other sectors of society, such as public services, restaurants, hotels and retail stores (Table 39).

The total value of wasted food is 1.3 billion € in the base case, while in the prevention case the value is 0.8 billion €. Figure 11 illustrates the sector-specific division between the purchase cost, usage cost and waste fees in these two cases.

Table 38. Total costs of food waste in the case regions in 2020 and the total cost savings of food waste prevention, M€ and €/capita.

	Helsinki region		Turku region		Salo region		Kymenlaakso		Total	
	M€	€/capita	M€	€/capita	M€	€/capita	M€	€/capita	M€	€/capita
Base case 2020	959	814	204	591	43	532	100	549	1306	732
Prevention case 2020	564	479	120	348	25	310	63	347	772	433
Total cost savings due to food waste prevention	395	335	84	243	18	222	37	202	534	299
Area's share of the total savings	74%		16%		3%		7%		100%	

Table 39. Total costs of food waste in different sectors in 2020 and the total cost savings of food waste prevention, M€ and €/capita.

	Households		Public sector		Retail		Private sector		Total	
	M€	€/capita	M€	€/capita	M€	€/capita	M€	€/capita	M€	€/capita
Base case 2020	491	275	185	104	321	180	308	173	1306	732
Prevention case 2020	273	153	114	64	201	113	179	100	772	433
Total cost savings due to food waste prevention	216	121	69	39	120	67	129	72	534	299
Sector's share of the total savings	40%		13%		22%		24%		100%	

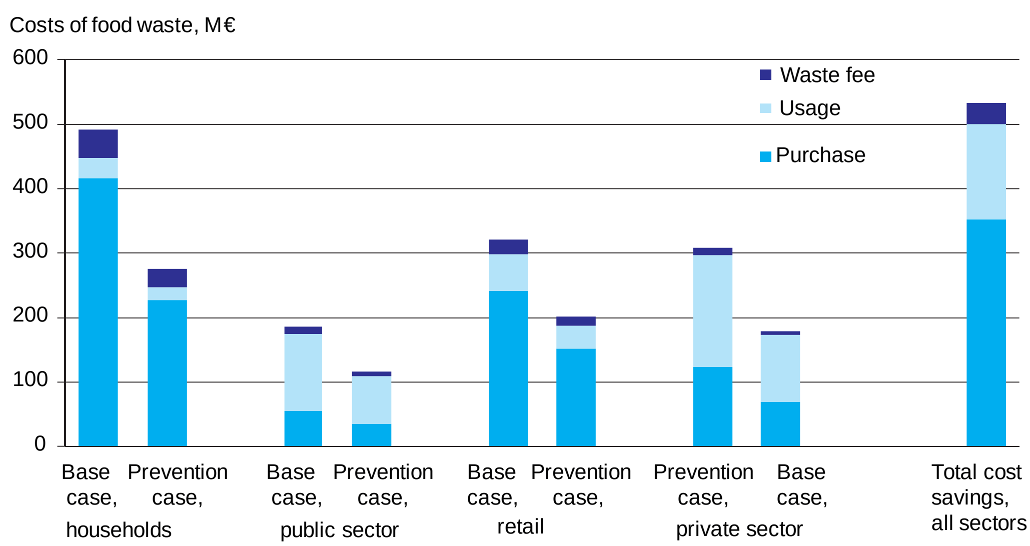

Figure 11. Costs of food waste divided into different cost components in different sectors and cases and the total cost savings in 2020.

3.1.4 Conclusions on food waste prevention

Achieving the food waste prevention target will decrease greenhouse gas emissions by 415 000 CO_2-eq tons in all of the sectors and case regions in 2020. Most of the savings are achieved through the reduction in unnecessary food production, processing and delivery to retail. Also, food waste prevention saves money for the waste generators, all in all almost 300 € on average per capita in 2020 (all sectors included). The cost savings depend on the sector-specific food waste compositions and total cost structures, the division of the target between the edible and inedible parts of the food waste and the case region-specific base case forecasts.

Waste prevention seems deservedly to be the first priority of the waste hierarchy in the case of food waste. The reason for this is that the combined avoided emissions in the early phase and usage phase achieved through the decrease in waste volume are significantly higher than the avoided emissions of the waste management phase that were caused by the change in waste management method. To determine the total effects of biowaste prevention the analysis should be extended to other biowaste fractions, such as tissue papers and garden waste, and other environmental effects should be analysed as well.

3.2 Theoretical biogas potential in all case regions

The amount of potential biomass for biogas production was determined (Fig. 12 and Table 40) and the amount of biogas energy that could be theoretically produced from these materials was calculated (Fig. 13). Biowaste, wastewater sludge, manure, crop residues and energy crops from available lands were included. In the studied case regions, in total 1.25 million tTS/a biomass could be available in 2020. In the Turku, Salo and Kymenlaakso regions, silage and other agricultural materials account for 94%, 98% and 91%, respectively, of the total theoretical biogas potential. The Helsinki region waste materials represents 65% of the biogas potential.

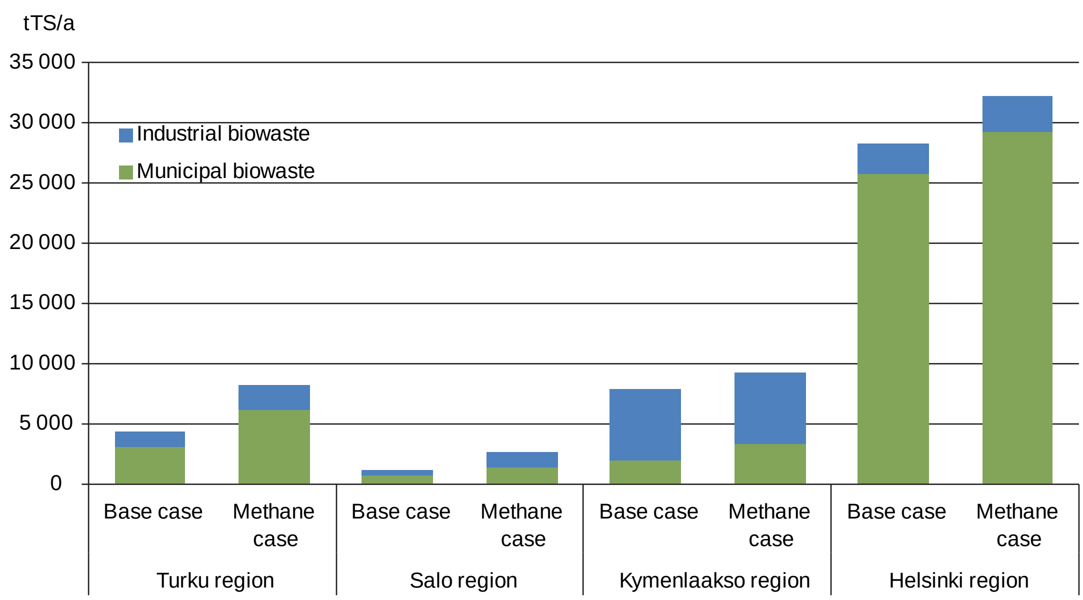

Figure 12. The amount of biowaste in the studied regions in the base case and methane cases 2020.

Table 40. Amount of different biomass (tTS/a) in the studied regions in the methane case 2020.

	Turku region	Salo region	Helsinki region	Kymenlaakso region	Total
Biomass	tTS/a				
Municipal biowaste	6 200	1 400	29 300	3 400	40 300
Industrial biowaste	2 000	1 300	3 000	5 900	12 200
WWTP suldge	12 000	1 550	43 400	43 600	100 500
Manure	54 300	26 600	2 800	38 100	122 000
Silage	201 414	176 515	25 176	197 256	600 400
Agricultural waste and side products*	125 992	112 142	15 556	117 227	371 000
Total	402 000	320 000	119 000	405 000	1 250 000

*straw, vegetables, greenhouse waste, potato waste, sugar beet

Table 41 presents the biomasses and potential amounts of energy that could be produced if all the available material were to be used for biogas production. This amount of biomass could be treated in several large-scale biogas plants and in total over 300 000 vehicles could use biomethane as vehicle fuel. A large portion of biomass is from agricultural sources so either the biomass or produced biomethane should be transported closer to possible users.

Table 41. Total energy and number of plants (4MW) and vehicles if all potential biomass is treated in biogas plants and upgraded to vehicle fuel.

	tTS/a	GWh/a	Number of 4 MW plants	Number of passenger vehicles
Turku	402 000	1 030	32	104 200
Salo	319 500	830	25	83 500
Helsinki	119 200	320	10	32 200
Kymenlaakso	420 800	990	31	100 500

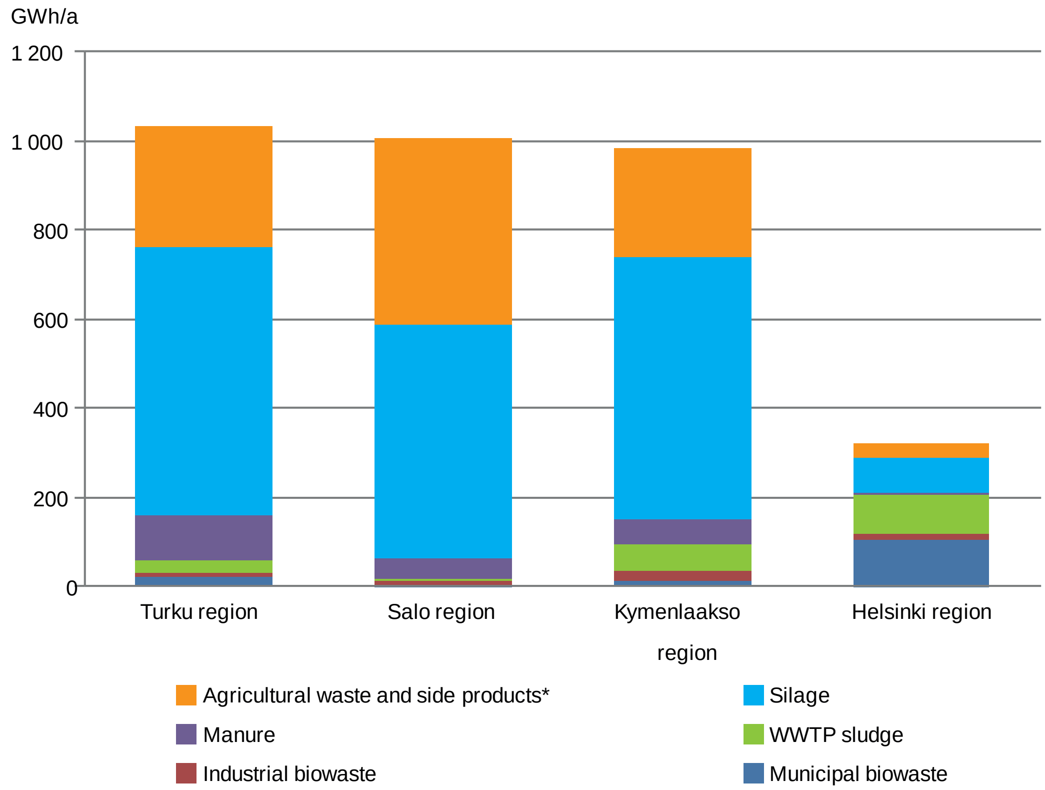

Figure 13. Amount of energy that could be produced from biomass and waste materials in the studied regions in the methane case for the year 2020.

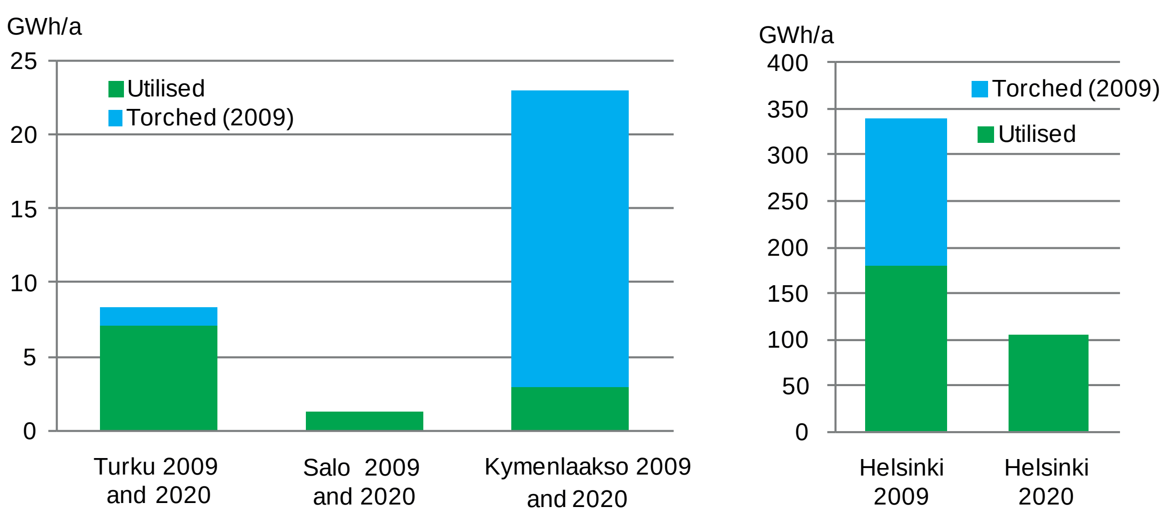

Figure 14. Recovered and utilised landfill gas in the studied regions in 2009 and 2020.

The amount of landfill gas is expected to be at the same level in 2020 in the studied regions as in 2009, except in the Helsinki region where the prediction for gas production in the year 2020 is 1 GWh lower that in the year 2009 (Fig. 14). Also, in other regions, gas production from old gas collection systems is expected to decrease but as there are plans for new gas collecting systems, the total gas amount is assumed to remain at the same level. In the long run, the amount of landfill gas is expected to decrease and eventually drop to zero as the amount of biowaste dumped to landfill declines.

3.3 Sites for methane production

To show the regional distribution of methane potential every biomass source was plotted onto the map with attributes indicating the amount and type of its biogas potential. The Density application of ArcGIS Spatial Analyst was used to find areas with relatively high concentrations of methane that could be suitable locations for biogas reactors. Figure 15 shows the density of methane potential within the Turku, Salo and Kymenlaakso case regions.

Potential site locations for biogas plants were derived by taking the spatial distribution of biomass sources and the location of the natural gas grid into consideration. For each potential site collection areas were derived using a maximal transportation distance of 10 kilometres and the amount of biomass that is available within those areas was calculated to determine the plants' production capacity. Furthermore transportation distances were calculated, including the raw material transportation to the production site, the digestate transportation from the plant to available spreading fields and the methane transportation to demand locations. Based on this information each potential site was assessed, taking environmental and economical production parameters such as production costs and formed greenhouse emissions into consideration, with the aim of identifying the most suitable production sites.

For the Helsinki region only agricultural materials were plotted onto the map (Fig. 16) as the sites for waste material treatment plants were already known.

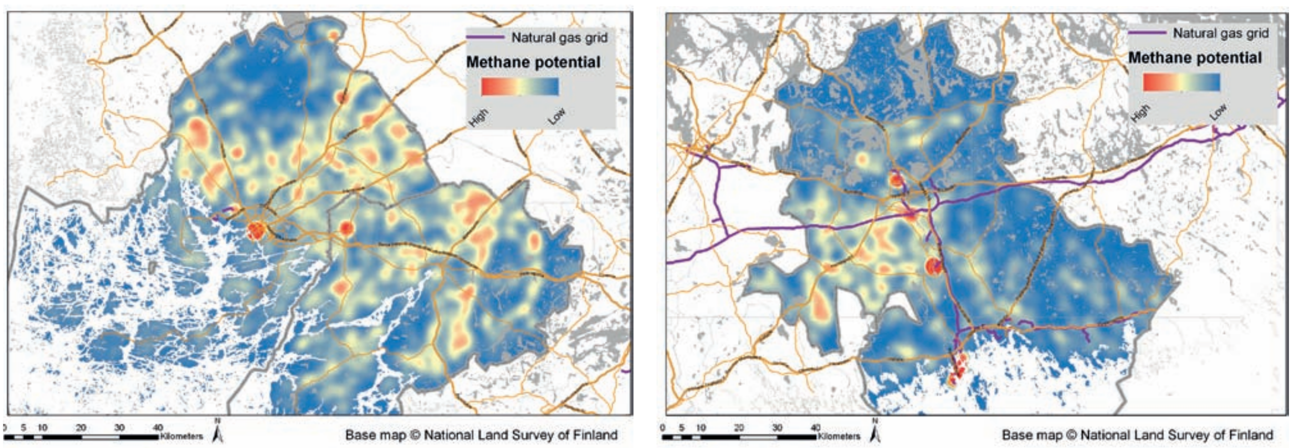

Figure 15. Spatial distribution of methane potential in the Turku, Salo and Kymenlaakso case regions. The orange and red areas represent high methane potential.

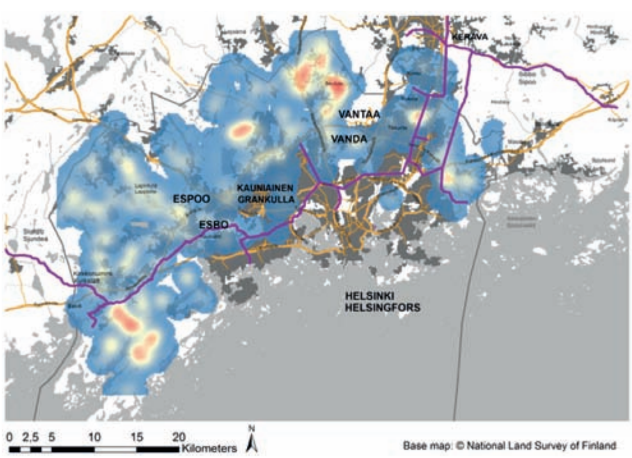

Figure 16. The distribution of agricultural materials in Helsinki region.

4 Turku, Salo and Kymenlaakso regions

4.1 Potential biogas plants

For the Turku, Salo and Kymenlaakso case regions, 22, 13 and 14 potential production sites were defined, respectively (Fig. 17). The characteristics of each site including the potential methane production, feedstock amount and feedstock composition are presented in Tables 42, 43 and 44.

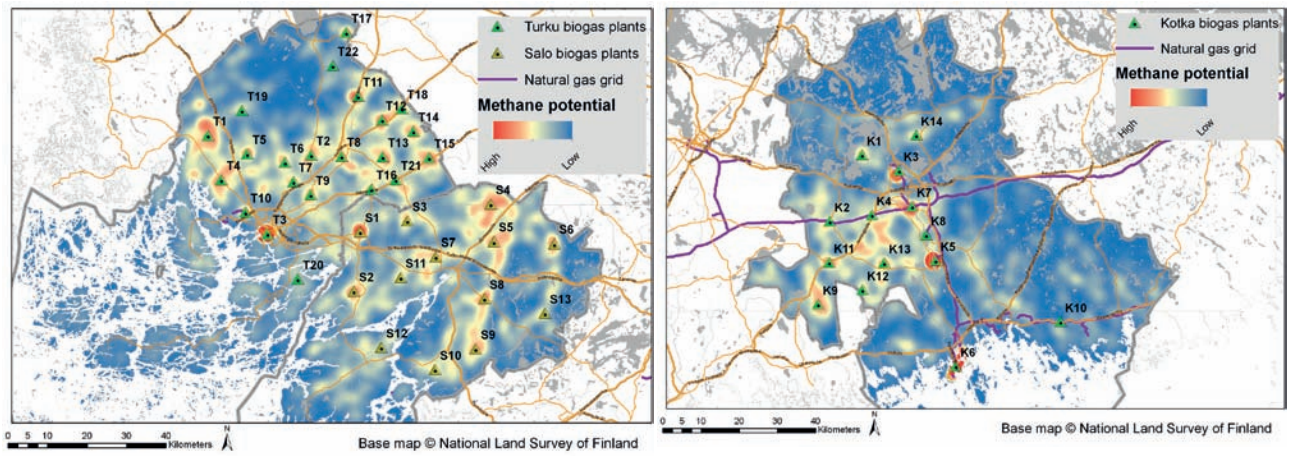

Figure 17. Biogas plant candidates in the Turku, Salo (left) and Kymenlaakso (right) regions.

Table 42. Descriptions of biogas plant candidates in the Turku region.

Plant ID	Plant size (MW)	Feedstock (tTS)	Feedstock composition (%)			
			Biowaste	Sludge	Manure	Field biomass
T1	7.0	22,000	0	0	19	81
T2	4.5	13,900	0	0	6	94
T3	7.4	23,100	20	52	2	26
T4	7.1	21,800	1	0	12	87
T5	5.7	17,900	0	0	16	83
T6	3.8	11,900	0	0	10	90
T7	3.1	9,300	1	0	1	98
T8	6.7	21,300	1	0	20	79
T9	6.2	19,100	1	0	10	89
T10	2.6	7,000	23	0	3	74
T11	5.9	19,100	0	0	31	69
T12	4.2	13,200	0	0	22	78
T13	3.2	10,100	0	0	16	84
T14	3.2	9,800	0	0	8	93
T15	4.8	14,900	0	0	9	91
T16	2.7	8,500	0	0	19	81
T17	2.1	7,000	0	0	39	61
T18	2.7	8,400	0	0	13	87
T19	3.4	10,900	0	0	24	76
T20	2.8	8,600	2	0	3	94
T21	5.8	18,000	0	0	11	89
T22	2.8	9,000	0	0	19	81
TOTAL	97.7	305,000				

Table 43. Descriptions of biogas plant candidates in the Salo region.

Plant ID	Plant size (MW)	Feedstock (tTS)	Feedstock composition (%)			
			Biowaste	Sludge	Manure	Field biomass
S1	6.7	19,500	7	0	10	83
S2	6.3	19,300	0	0	10	90
S3	4.3	13,600	0	0	19	81
S4	8.4	25,900	0	0	6	94
S5	8.1	25,200	0	0	8	92
S6	5.4	17,000	0	0	16	84
S7	6.6	20,300	3	7	4	86
S8	6.5	19,900	1	0	5	94
S9	4.7	14,400	0	0	2	98
S10	5.0	15,400	0	0	13	87
S11	4.5	14,000	0	0	9	91
S12	4.2	12,800	0	0	4	96
S13	4.0	12,300	0	0	2	98
TOTAL	74.6	230,000				

Table 44. Descriptions of biogas plant candidates in the Kymenlaakso region.

Plant ID	Plant size (MW)	Feedstock (tTS)	Feedstock composition (%)			
			Biowaste	Sludge	Manure	Field biomass
K1	2.6	8,100	0	0	9	91
K2	6.0	18,500	0	0	2	97
K3	3.8	19,600	8	59	2	30
K4	7.4	23,300	0	0	9	91
K5	7.0	27,200	0	55	2	42
K6	5.9	21,600	24	70	0	6
K7	3.6	10,600	9	18	2	71
K8	4.8	15,300	1	0	13	86
K9	4.8	15,000	0	0	9	90
K10	2.5	8,200	0	0	17	83
K11	6.4	20,200	0	0	11	89
K12	3.3	10,600	0	0	13	87
K13	7.4	23,300	0	0	8	92
K14	3.8	12,400	0	0	15	85
TOTAL	69.2	234,000				

4.2 Environmental impact assessment

4.2.1 Emission factors in the base and methane cases

Emission factors related to raw material procurement and fuel use for every raw material used were calculated in the base and methane cases. In the case of biogas plant-related emissions, raw material transportation was not included in the emission factors.

Emission factors for the base and methane cases in each region are presented in 45. The base case emission factors include the emissions caused by the raw material procurement and the part of the traffic emissions (also taken into account in fuel production) that could be replaced by produced biomethane (in the methane case). The emission factors used in the methane case include raw material procurement and the biomethane traffic emissions. The emission factors of biowaste in different regions differ due to the different biowaste treatment technologies used in the base case but also because of the different methane potentials of different biomasses. For example, for bakery waste, which has a high methane potential, the emission factor for the procurement phase is only 48 kg CO_2-eq/t raw material but when diesel and petrol vehicle emissions are included, the emission factor increases. For other raw materials, the same raw material procurement emission factors were used in both cases, but traffic emissions differ in the methane case. This is because the amounts of biomethane produced from different materials vary, and therefore provide different amounts of biomethane kilometres and replace different amounts of diesel and petrol.

The results show the difference between raw materials that have high and low methane production potential. For example the emission factor for the liquid manure of cattle is only 44 kg, CO_2-eq./t compared to the emission factor for Kymenlaakso biowaste, which is 117 kg, CO_2-eq./t when the emission factors are calculated per mass of raw materials. Instead, the emission factor for the liquid manure of cattle is 122 g, CO_2-eq./MJ, biomethane and for Kymenlaakso biowaste only 33 g, CO_2-eq./MJ, biomethane, when the emission factors are calculated according to the biomethane production potential of raw materials (Table 46).

Table 45. Emission factors of different biomasses in the base and methane cases.

	Base case [kg, CO_2-eq./t,raw material			Methane case [kg, CO_2-eq./t,raw material		
	Kymenlaakso	Salo	Turku	Kymenlaakso	Salo	Turku
Biowaste	357	331	337	117	264	233
Bakery waste	782	765	765	607	607	607
Liquid manure, cattle	80	79	79	44	44	44
Dry manure, cattle	156	155	155	66	66	66
Liquid manure, pig	104	103	103	51	51	51
Dry manure, pig	274	270	270	82	81	81
Dry manure, horse	598	255	255	99	99	99
Dry manure, poultry	361	355	355	102	102	102
Straw	587	575	575	83	83	83
Crop residues	126	123	123	30	30	30
Municipal waste water sludge	142	139	139	144	144	144
Forest industry, primary sludge	130	127	127	31	31	31
Forest industry, biosludge	43	42	42	29	29	29
Silage				113	113	113

Table 46. Emission factors in the methane case per MJ of biomethane.

	Emission factor [g, CO2-eq./ MJ, biomethane		
	Kymenlaakso	Salo	Turku
Biowaste	33	76	67
Bakery waste	71	71	71
Liquid manure, cattle	122	122	122
Dry manure, cattle	80	80	80
Liquid manure, pig	140	140	140
Dry manure, pig	39	39	39
Dry manure, horse	57	57	57
Dry manure, poultry	35	35	35
Straw	13	13	13
Crop residues	23	23	23
Silage	30	30	30
Municipal wastewater sludge	95	95	95
Forest industry, primary sludge	20	20	20
Forest industry, biosludge	57	57	57

Biowaste

In the base case, emissions from different biowaste treatment technologies account for the bulk of emissions caused by electricity usage in processes. In the methane case, compensating for electricity and heat, which were produced at an incineration plant in the base case, has the most important effect in every region. The use of reject as soil amendment also produces substantial emissions. Based on these results, it can be assumed that if the decrease in the amount of energy produced by incineration plants were to be replaced with renewable energy, for example wind electricity and heat from chip boilers, the emission factor for biowaste would be significantly lower.

Bakery waste

In the base case, emissions related to bakery waste are caused by electricity and heat usage in ethanol production. Ethanol car emissions are not taken into account, because the CO_2 emissions are bio-based. In the methane case the biggest emissions are caused when ethanol is replaced with petrol. Based on this result, it can be assumed that the emission factor for bakery waste would be significantly lower if bioethanol were to be replaced with bio-based fuels, for example biogas.

Manure

In both the base case and methane case, the emissions from manure storage and the soil cause the largest share of total emissions. However, in the methane case, the storage emissions are estimated to be 60% lower than in the base case due to different storage methods. Although soil emissions are a little higher in the methane case, the benefit is that the biogas process improves the soluble nitrogen content of manure, which means that more mineral fertilisers can be replaced. It is quite difficult to estimate the emissions from soil. However, the emissions from electricity usage in the methane case are also significant, which means that the total emissions from the manure chain can be affected by choosing the electricity production method with the lower emission factor.

Silage
In the methane case emissions related to the soil, harvesting and electricity usage are in an equal role.

Straw and agricultural by-products
In the base case, emissions are caused by the decomposition of straw, tops and other agricultural waste and by-products. In the methane case the emissions from soil and electricity usage are notable. Electricity usage in the methane case depends on the produced biogas amount and straw has a high methane production potential. Due to the high dry matter content of straw, emissions from straw harvesting, caused by diesel usage, are also noticeable.

Municipal waste water sludge
In the base case, the emissions are caused by gas turbines, because it is assumed that wastewater treatment plants produce their own energy by using biogas produced from digested municipal wastewater sludge. In the methane case, the energy of the wastewater treatment plants has to be compensated. In our calculation we used Finnish average electricity and district heating. Therefore the emissions of compensated energy production stand out most in the total emission factor. A sensitivity analysis was made, and the results showed that if electricity were to be compensated with wind power (zero emissions) and heat were to be produced in chip boilers, the total emission factor would decrease by approximately 90 kg, CO_2-equivalent/t, sludge.

Forest industry, primary and bio sludge
In the base case the forest industries' sludge is burnt in an incineration plant. The emissions related to incineration plants are not taken into account and the energy output from forest industry sludge used without drying is so low that the compensated energy need in the methane case is also excluded. Therefore the main sources of total emissions are the use of reject in soil and electricity usage in the biogas production process.

4.2.2 Total emissions
The emission factors calculated above were used to calculate total emissions for the base and methane cases and the effects of the methane case on emissions in the Kymenlaakso, Salo and Turku regions. Total emissions in the methane case are 129 330 t,CO_2, 133 260 t,CO_2 and 173 320 t,CO_2 lower than in the base case in Kymenlaakso, Salo and Turku, respectively. Total emissions by life cycle phases are presented in Table 47. Table 47 also presents the energy balance, which means that the energy consumption in the base and methane cases and also energy production in the methane case are calculated. Energy consumption means the total energy used by the studied systems, including electricity, heat and fuel energy. Energy production in the methane case means the energy content of the produced biomethane. Based on these, the amount of energy consumed is approximately 20% of the energy produced.

Table 47. Total annual CO_2-equivalent emissions and energy balance in the base and methane cases in 2020 in the target regions (if all potential biogas plants are built in 2020).

Base case		Kymenlaakso	Salo	Turku
Raw material transportation	t, CO2	6	3	12
Raw material procurement	t, CO2	13 500	15 050	26 790
Petrol/diesel car traffic emissions	t, CO2	178 720	180 480	239 410
Total	t, CO2	192 220	195 520	266 200
Energy consumption	MWh	9 640	1 650	3 760
Methane case		Kymenlaakso	Salo	Turku
Raw material transportation	t, CO2	360	460	480
Raw material procurement	t, CO2	57 320	56 260	84 870
Biomethane transportation	t, CO2	-	290	490
Reject transportation	t, CO2	380	310	480
Biomethane traffic use	t, CO2	4 830	4 940	6 550
Total	t, CO2	62 890	62 260	92 880
Energy production	MWh	553 770	598 440	785 300
Energy consumption	MWh	109 540	108 340	171 940
Energy consumption/Energy production		20 %	18 %	22 %
Emission decrease from base to methane case	t, CO2	129 330	133 260	173 320

Figure 18 presents the total emissions in the base and methane cases divided into different life cycle phases based on the values in Table 46. The emissions from raw material procurement are higher in the methane case, but the total emissions are lower due to petrol and diesel use in the base case.

Figure 19 presents more detailed total emissions for the base and methane cases in every region. Raw material processing is in a minor role when comparing the emissions caused by petrol and diesel production and use. The amount of petrol and diesel needed as traffic fuel depends on the amount of biomethane produced in the methane case. Therefore emissions related to petrol and diesel production and use play a remarkable role when biomethane is produced in the methane case. Raw material transportation emissions accounted for only 1-2% of the total emissions. In the methane case the emissions related to raw material procurement are higher than in the base case but total emissions are lower in the methane case, because the emissions from fossil diesel and petrol use are much higher in the base case.

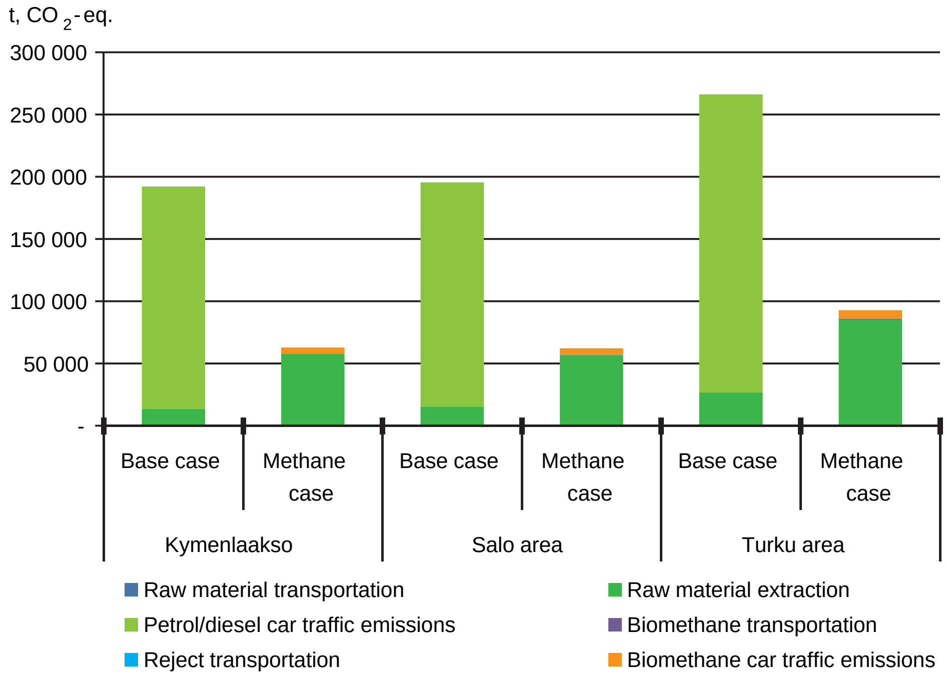

Figure 18. Total emissions in the base and methane cases divided into life cycle phases.

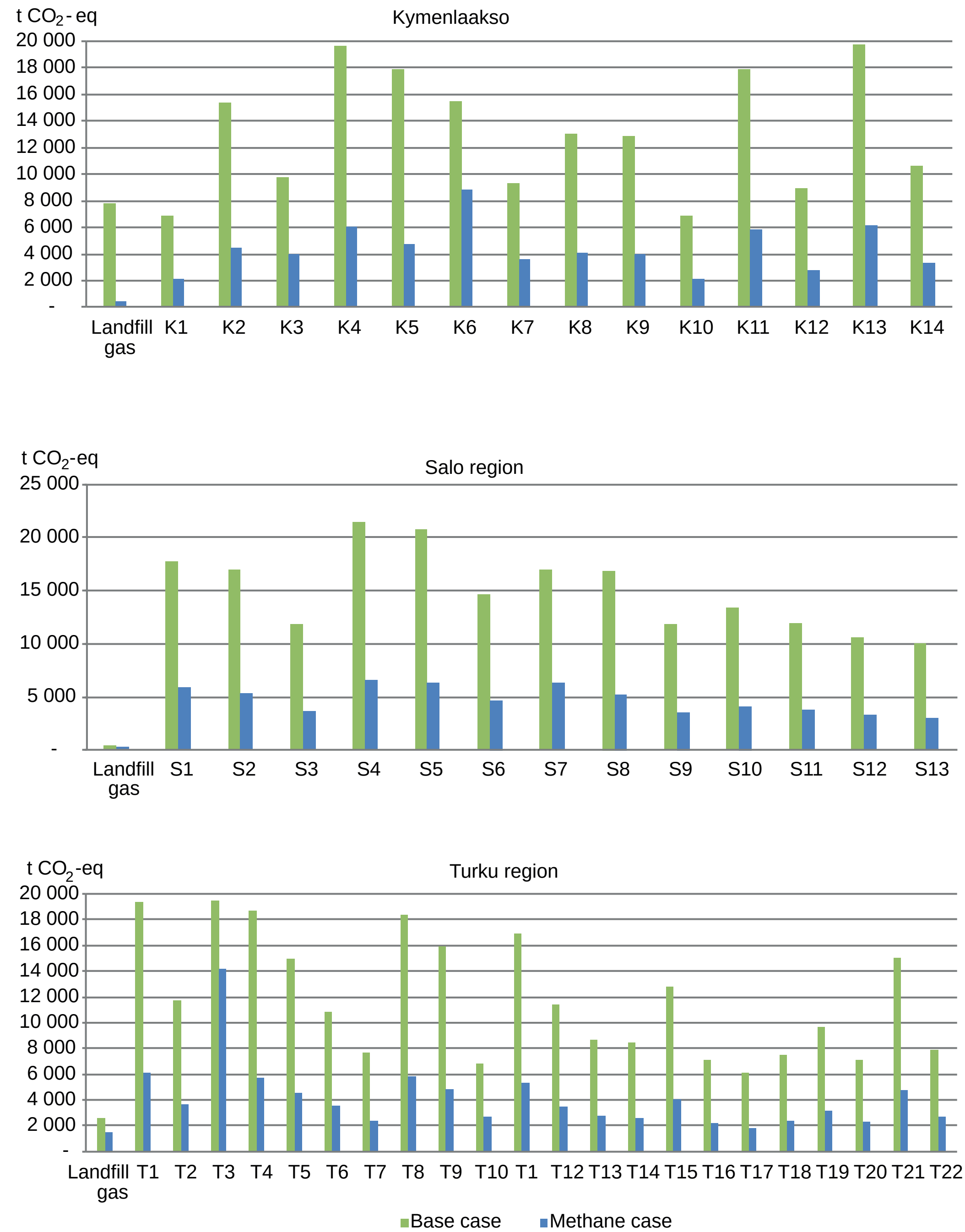

Figure 19. CO_2-equivalent emissions in the base and methane cases for individual biogas plants in the Kymenlaakso, Turku and Salo regions.

4.3 Economic and regional impact assessment

4.3.1 Consumption and capacity building of biomethane

The possible growth in biomethane use in vehicles was assessed in the case regions and based on these assessments the needed capacity of biogas plants was determined. In the assessment of biomethane consumption growth, the Turku and Salo regions are counted as a connected market area. This is because the consumption potential in the Salo region is relatively limited compared to its biomethane production potential. Thus, consumption growth paths and the needed upgrading capacity are expressed here for both regions.

The Kymenlaakso region can feed biomethane to the natural gas grid, which enlarges the market area remarkably. But if incentives for biomethane deployment are created, it is likely that the development of biomethane production will grow correspondingly, not only in the case regions of this research, but in all the areas connected to the gas grid, which reduces the opportunities to achieve a larger market share in the Kymenlaakso region. However there is a potential market in the Helsinki region.

Two scenarios were studied: a moderate growth path and a fast growth path. In the moderate growth path 1.5% of the vehicle stock is converted to biomethane within a ten-year period. The fast growth path is based on the assumption that about every fourth new vehicle would be methane-fuelled, a yearly regional growth rate of around 1% of the total vehicle stock, which would lead to a 10% market share within a ten-year period (Fig. 20).

For the moderate growth path, it is only necessary to build one unit (Turku ID T3). The upgrading unit could feed for example all the consumption of local busses in the Turku region. For fast growth, a capacity of 9 units is needed within a 10-year period (Fig. 21). This could for example mean that all the local busses and waste trucks, 50% of taxis and 15% of passenger cars would be driven with biomethane in the Turku and Salo regions.

It is notable that the mapped production potential is considerably higher. The total regional potential is 42% of the total vehicle stock. In GIS-based biomass mapping upgrading units were sited in hotspots of biomethane production potential, and the transport distance of agricultural biomasses was cut to a maximum of 10 kilometres. Thus the potential corresponds to about 25% of the total vehicle stock in the region. In the moderate growth path it would take 168 years and in the fast growth path 25 years to meet this production level.

When connected to the natural grid, the market area of biomethane grows to cover all areas that are sited close to the gas grid. This can grow the market potential remarkably, but expecting biomethane production to be profitable, biomethane production is likely to grow accordingly in all areas connected to the gas grid.

For the moderate growth path, it is only necessary to build one unit in Kotka (ID T6), including the Heinsuo landfill. The upgrading unit could feed for example all consumption of local busses and waste trucks, 50% of taxis and 3% of passenger cars. For fast growth, a capacity of 6 units is needed within a 10-year period (Fig 22). This could for example mean that all the local busses and waste trucks, 50% of taxis, 10% of trucks and 24% of passenger cars would be driven with biomethane in the Kymenlaakso region.

In the Kymenlaakso region upgrading units can be connected to the natural grid. Thus, there is no need to cover under-consumption of biomethane as a transport fuel with low profitability CHP, since all biomethane can be fed to the natural gas grid. However, the producer price of biomethane is much lower if it is not used as transport fuel. Building overcapacity with upgrading increases the production costs of biomethane remarkably. Therefore one should have a realistic view of the growth rate of biomethane consumption.

It is notable that the mapped production potential is considerably higher. The total potential in the Kymenlaakso region is 48% of the total vehicle stock. In GIS-based biomass mapping, upgrading units were sited in hotspots of biomethane production potential, and the transport distance of agricultural biomasses was cut to a maximum of 10 kilometres. Thus the potential corresponds to about 29% of the total vehicle stock in the region. In the moderate growth path it would take 194 years and in the fast growth path 29 years to meet this production level.

Biomethane production units that are needed to meet consumption growth in the moderate and fast growth paths within a 10-year period are expressed in order of profitability (Table 48 for the Turku and Salo regions, Table 49 for Kymenlaakso). Knowing that consumption of biomethane will not directly reach the level of a single unit's production capacity, the cost of production is expressed for a 10-year transition period, where the production cost is an average, weighed with the biomethane production amount of each year. Thus, full consumption of a single plant's production capacity is expected to be achieved gradually, starting from 10% usage in the first year. The rest of the biogas production capacity is used for CHP production in the Turku and Salo regions and in Kymenlaakso the rest of the biomethane is expected to be fed into the natural gas grid at a producer price of 40 €/MWh th. The price of biomethane sold for use as transport fuel is expected to be 100 €/MWh.

It is notable that when the market has matured – at which point upgrading can be run with full power and all biomethane can be sold as transport fuel – the production cost of biomethane is 17 -36 €/MWh lower in Turku and Salo and in Kymenlaakso 6 €/MWh depending on the composition of the raw materials used in digestion. This shows promising prospects for the future of using biomethane as a transport fuel. The challenge is in creating a market for currently non-standard technology that is not compatible with existing vehicle and refuelling capacity.

Production cost is highly dependent on the composition of the raw materials digested by the plants (Table 42, 43 and 44). The biogas plants that run with a high content of biowaste and sludge are remarkably profitable, with expected gate fees of 70 €/t biowaste and 30 €/t sludge. However, it can be presumed that gate fees will decline, even close to zero, and in a highly competitive situation will even turn negative. This obviously depends strongly on the development of the sector and the prospective support scheme for biomethane.

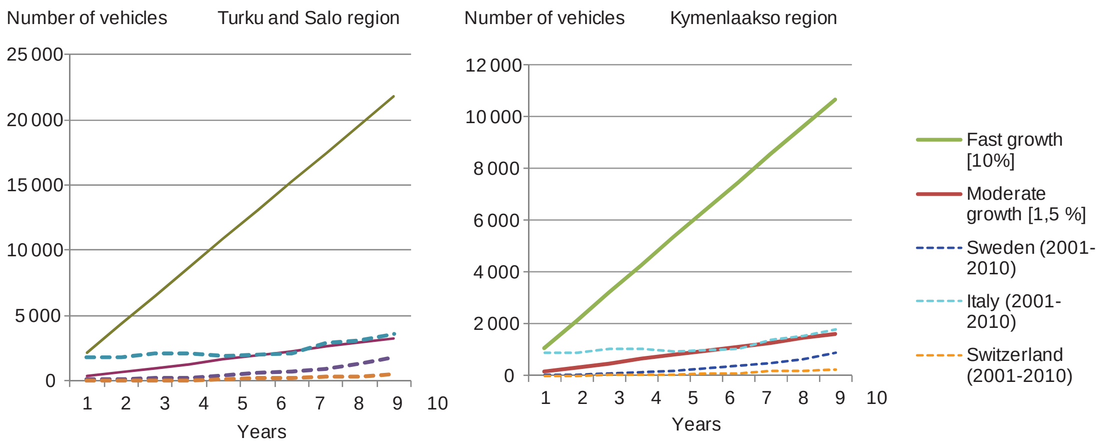

Figure 20. Growth rate path of methane driven vehicles in the Turku and Salo region (left) and Kymenlaakso (right) compared to relative growth in the number of methane vehicles in selected countries within a ten-year period.

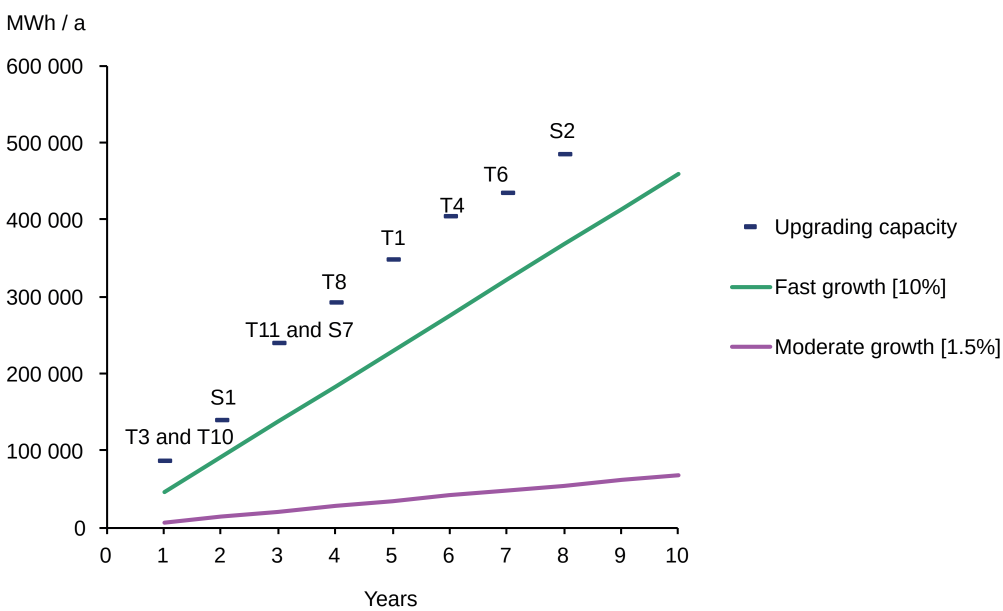

Figure 21. Growth paths of biomethane and the need to build new capacity to meet biomethane consumption in the Turku and Salo regions.

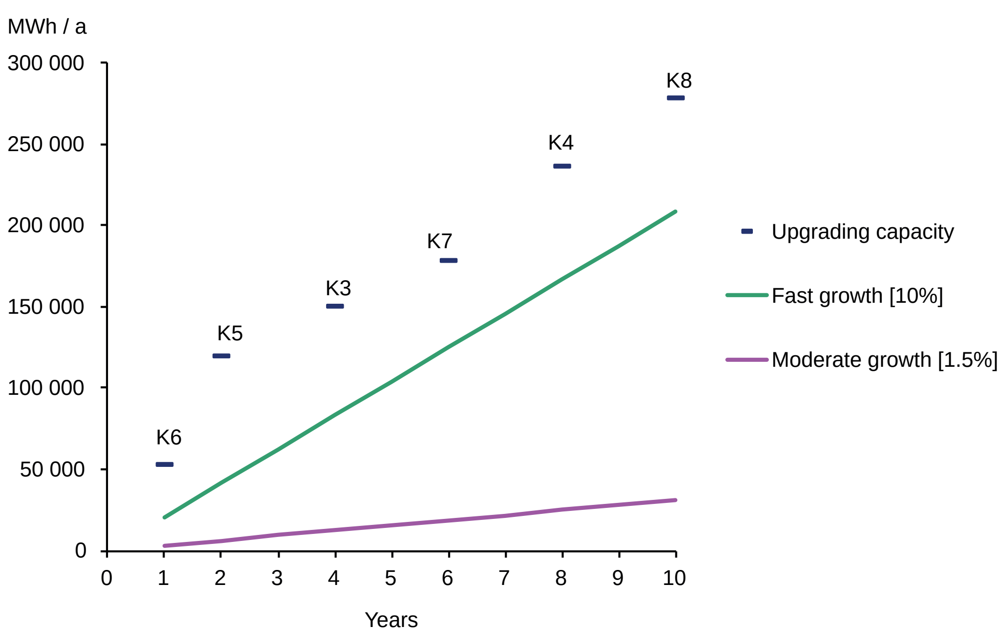

Figure 22. Growth paths of biomethane and the need to build new capacity to meet biomethane consumption in the Kymenlaakso region.

In Table 48 and 49, the cost of biomass means the transport and harvesting costs of field biomasses. Biogas production includes transport of other raw materials, as well as return freight and field spreading of digestate. In the Turku and Salo regions, biomethane delivery includes biomethane transport by road and refuelling costs. In Kymenlaakso biomethane delivery includes the cost of the gas pipeline, gas grid connection, gas grid fee and refuelling.

The producer price of biomethane is expected to be 100 €/MWh, electricity 45 €/MWh and heat 30 €/MWh. The usability of the sold heat is 30%. The producer price is expected to be 40 €/MWh th when sold to the natural gas grid.

Table 48. Capacity building order and costs of biomethane production in the Turku and Salo regions.

TURKU AND SALO REGIONS													
	Moderate growth 1.5 %		Fast growth path 10%										
	Plant ID	T3 and Topinoja landfill	T10	T11	T8	T1	T4	T6	Total / average (TURKU)	S1	S7	S2	Total / average (SALO)
Capacity building order													
Moderate growth, 1.5% at 10 years	Year	1											
Fast growth, 10 % at 10 years	year	1	1	3	4	5	6	7		2	3	8	
Production scale													
Upgrading output power	MW	8.2	2.8	5.8	6.6	7.0	7.0	3.8	41	6.6	6.5	6.3	19
Production potential, 100%	GWh th/a	66	22	47	53	56	56	30	330	53	52	50	155
Average biomethane production,55%	GWh th/a	36	12	26	29	31	31	17	177	29	29	28	85
Raw materials	1000 t/a	91	18	57	62	72	63	43	407	60	58	68	185
Biowaste	%	18	30		1		1			6	4		
Sludge	%	65									13		
Manure	%	3	6	47	39	35	21	42		26	12	28	
Field biomass	%	15	64	53	60	65	78	57		67	72	72	
Investment													
Biogas production	Mill. €	9.4	2.8	6.3	7.2	7.6	7.6	3.9	45	6.7	7.5	6.8	21
Upgrading	Mill. €	3.1	1.5	2.3	2.5	2.6	2.6	1.8	16	2.5	2.5	2.4	7
Biomethane delivery	Mill. €	3.3	1.1	2.4	2.7	2.8	2.8	1.5	17	1.3	1.3	1.3	4
CHP	Mill. €	1.6	0.6	1.2	1.3	1.4	1.4	0.8	8	2.7	2.6	2.5	8
Total		16.9	5.9	12.2	13.6	14.4	14.4	8.0	86	13.2	13.9	13.0	40
Investment aid, 30%	Mill. €	5.1	1.8	3.6	4.1	4.3	4.3	2.4	26	4.0	4.2	3.9	12
Cost													
Biomass	Mill. €/a	-0.2	-0.2	-0.5	-0.7	-0.6	-0.7	-0.4	-3.3	-0.6	-0.7	-0.6	-1.9
Biogas production	Mill. €/a	-2.2	-0.5	-1.4	-1.5	-1.6	-1.6	-0.8	-9.6	-1.4	-1.5	-1.4	-4.3
Upgrading and delivery	Mill. €/a	-1.2	-0.4	-0.9	-0.9	-1.0	-1.0	-0.6	-5.8	-0.9	-0.9	-0.9	-2.8
CHP	Mill. €/a	-0.3	-0.1	-0.3	-0.3	-0.3	-0.3	-0.2	-1.9	-0.3	-0.3	-0.3	-0.9
Total	Mill. €/a	-3.8	-1.3	-3.0	-3.4	-3.6	-3.6	-2.0	-20.7	-3.3	-3.4	-3.3	-10.0
Income													
Gate fees	Mill. €/a	4.1	0.4	0.1	0.2	0.2	0.1	0.1	5.2	0.3	0.6	0.1	1.0
Biomethane	Mill. €/a	3.6	1.2	2.6	2.9	3.1	3.1	1.7	17.7	2.9	2.9	2.8	8.5
Electricity	Mill. €/a	0.5	0.2	0.4	0.4	0.5	0.5	0.2	2.6	0.4	0.4	0.4	1.3
Heat	Mill. €/a	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.5	0.1	0.1	0.1	0.3
Total	Mill. €/a	7.9	1.7	3.2	3.6	3.8	3.8	2.1	26.0	3.8	3.9	3.4	11.1
PROFIT (+) / LOSS (-)	Mill. €/a	4.10	0.46	0.18	0.16	0.16	0.19	0.08	5.3	0.51	0.48	0.12	1.1
Needed price of biomethane													
to cover production costs	€/MWh th	-24	57	93	94	95	94	95	70	83	83	96	87

Table 49. Capacity building order and costs of biomethane production in the Kymenlaakso region.

KYMENLAAKSO REGION								
	Moderate growth 1,5%		Fast growth path 10%					
	Plant ID	K6+ Heinsuo landfill	K5 + Keltakangas landfill	K3 + Karhukangas landfill	K7	K4	K8 + Sulento and Sammalsuo landfills	Total / average
Capacity building order								
Moderate growth, 1.5% at 10 years	Year	1						
Fast growth, 10% at 10 years	year	1	2	4	6	8	10	
Production scale								
Upgrading output power	MW	6.7	8.4	3.8	3.5	7.3	5.3	34.9
Production potential, 100%	GWh th/a	54	67	31	28	58	42	280
Average transport fuel production, 55%	GWh th/a	30	37	17	15	32	23	154
Raw materials	1000 t/a	70	82	57	30	64	44	349
Biowaste	%	14		6	11		1	
Sludge	%	82	61	67	31			
Manure	%		7	4	3	26	33	
Field biomass	%	4	32	23	55	74	66	
Investment								
Biogas production	Mill. €	8.4	9.5	7.0	4.4	7.9	5.3	42.5
Upgrading	Mill. €	2.5	3.1	1.9	1.7	2.7	2.2	14.1
Gas grid connection and refuelling	Mill. €	2.7	3.4	1.6	1.4	2.9	2.1	14.2
Total		13.6	15.9	10.5	7.6	13.5	9.6	70.8
Investment aid, 30%	Mill. €	4.1	4.8	3.1	2.3	4.1	2.9	21.2
Cost								
Biomass	Mill. €/a	-0.0	-0.4	-0.2	-0.3	-0.8	-0.5	-2.3
Biogas production	Mill. €/a	-2.0	-2.0	-1.5	-0.8	-1.6	-1.1	-9.0
Upgrading and delivery	Mill. €/a	-0.9	-1.2	-0.6	-0.5	-1.0	-1.0	-5.3
Total	Mill. €/a	-3.0	-3.6	-2.4	-1.7	-3.5	-2.6	-16.6
Income								
Gate fees	Mill. €/a	2.8	1.6	1.4	0.7	0.1	0.1	6.7
Biomethane, transport fuel	Mill. €/a	3.0	3.7	1.7	1.5	3.2	2.3	15.4
Biomethane, other	Mill. €/a	1.0	1.2	0.6	0.5	1.0	0.8	5.0
Total	Mill. €/a	6.8	6.4	3.6	2.8	4.3	3.2	27.1
PROFIT (+) / LOSS (-)	Mill. €/a	3.78	2.84	1.28	1.08	0.89	0.61	10.49
Needed price of biomethane								
to cover production costs	€/MWh th	-28	23	24	30	72	74	32

4.3.2 Regional effects

4.3.2.1 Effects in biowaste and sludge treatment

In the base case the amount of biowaste is forecast to grow in the Turku, Salo and Kymenlaakso regions by 7.4%, 4.3% and 0.8%, respectively, from the base year 2009. In the methane case, as a result of waste prevention actions, the biowaste amount is expected to decline by 30% by the year 2020 from the year 2009 level.

Tables 50, 51 and 52 present the costs of biowaste treatment and income from the production of biogas energy from biowaste. Because the focus is on regional effects, in the case of outsourced treatment only the costs of waste treatment and transport were taken into account.

The most expensive biowaste treatment is outsourced biogas (CHP) treatment (base case) (Tables 50, 51 and 52). This is because no income from energy production in biowaste treatment would be allocated to the region. In waste incineration only 1/3 of the heat production potential is utilised, resulting in a waste treatment cost of 125 €/t of biowaste. If the incineration plant were to have a continuous heat load, the cost of treatment would decline to 114 €/t. In the methane case, the cost of energy replacement comes from the difference between CHP production in the base case and methane case.

Clearly the most favourable option is biomethane production (methane case). If biomethane is sold as transport fuel to consumers at a price of 100€/MWh, energy production from biowaste would compensate for the costs of waste treatment. It is notable that the calculation is based on a situation where all biomethane is sold to the transport fuel market, which is unlike the situation in an emerging market. The calculation is simplified to clearly present the effect potential of different waste treatment options.

Table 50. Effects of biowaste treatment in the base case and methane case in the Turku region.

TURKU REGION 2020 - Population 344 213	TREATMENT OF BIOWASTE				
BASE CASE		Waste incineration No source separation	Biogas CHP Outsources treatment	Home composting source separated	Total amount of biowaste
Amount of biowaste	t/a	39 000	8 300	6 900	54 200
Energy production					
Energy content, LHV	MWh th	31 200			31 200
Heat, usability 33%	MWh th	6 821			6 821
Power	MWh el	5 921			5 921
Specific costs / incomes					
Waste treatment	€/t	-72	-76		
Waste transport	€/t	-65	-86		
Heat	€/MWh th	30			
Power	€/MWh el	45			
Profit (+) / loss (-)					
Cost of treatment	1000 €/a	-5 343	-1 345		-6 688
Income from energy production	1000 €/a	471			471
Total	1000 €/a	-4 872	-1 345		-6 217
	€/t biowaste	-125	-162		-115
Net effect per capita	€ / a	-14.2	-3.9		-18.1
METHANE CASE		Waste incineration No source separation	Biogas biomethane source separated		Total amount of biowaste
Amount of biowaste	t/a	9 200	26 200		35 400
Energy production					
Energy content, LHV	MWh th	7 360	20 960		28 320
Biomethane	MWh th		28 296		28 296
Heat, usability 33%	MWh th	1 609			1 609
Power	MWh el	1 397			1 397
Specific costs / incomes					
Waste treatment / Digestion	€/t	-72	-35		
Waste transport	€/t	-65	-35		
Upgrading	€/MWh th		-20		
Gas transport and refuelling	€/MWh th		-15		
Heat	€/MWh th	30			
Power	€/MWh el	45			
Biomethane	€/MWh th		100		
Profit (+) / loss (-)					
Cost of waste treatment	1000 €/a	-1 260	-2 824		-4 085
Cost of energy replacement	1000 €/a				-360
Income from energy production	1000 €/a	111	2 830		2 941
Total	1000 €/a	-1 149	5		-1 504
	€/t biowaste	-125	0		-42
Net effect per capita	€ / a	-3.3	0.0		-4.4

Table 51. Effects of biowaste treatment in the base case and methane case in the Salo region.

SALO REGION 2020 - Population 80 828	TREATMENT OF BIOWASTE				
BASE CASE		Waste incineration No source separation	Biogas CHP Outsources treatment	Home composting source separated	Total amount of biowaste
Amount of biowaste	t/a	11 300	3 800		15 100
Energy production					
Energy content, LHV	MWh th	9 040			9 040
Heat, usability 33%	MWh th	1 976			1 976
Power	MWh el	1 716			1 716
Specific costs / incomes					
Waste treatment	€/t	-72	-76		
Waste transport	€/t	-65	-86		
Heat	€/MWh th	30			
Power	€/MWh el	45			
Profit (+) / loss (-)					
Cost of treatment	1000 €/a	-1 548	-616		-2 164
Income from energy production	1000 €/a	136			136
Total	1000 €/a	-1 412	-616		-2 027
	€/t biowaste	-125	-162		-134
Net effect per capita	€ / a	-17.5	-7.6		-25.1
METHANE CASE		Waste incineration No source separation	Biogas biomethane source separated		Total amount of biowaste
Amount of biowaste	t/a	3 200	7 300		10 500
Energy production					
Energy content, LHV	MWh th	2 560	5 840		8 400
Biomethane	MWh th		7 884		7 884
Heat, usability 33%	MWh th	560			560
Power	MWh el	486			486
Specific costs / incomes					
Waste treatment / Digestion	€/t	-72	-35		
Waste transport	€/t	-65	-35		
Upgrading	€/MWh th		-20		
Gas transport and refuelling	€/MWh th		-15		
Heat	€/MWh th	30			
Power	€/MWh el	45			
Biomethane	€/MWh th		100		
Profit (+) / loss (-)					
Cost of waste treatment	1000 €/a	-438	-787		-1 225
Cost of energy replacement	1000 €/a				-98
Income from energy production	1000 €/a	39	788		827
Total	1000 €/a	-400	1		-496
	€/t biowaste	-125	0		-47
Net effect per capita	€ / a	-4.9	0.0		-6.1

The bottom of Tables 50, 51 and 52 features an indicator, net effect per capita (€/a), which represents the beneficiary order among the treatment options. It is not limited only to cost/benefit of waste treatment per ton, but also takes into account the change in total waste amount per capita. As the total effect, the cost of biowaste treatment in the methane case is about 14 to 19 €/capita lower than in the base case.

The amount of sludge in the Turku and Salo regions is expected to remain at the same level in both cases in 2020 (Tables 53 and 54). In the Kymenlaakso region the amount of sludge is expected to decline by 25% due to changes in the structures of industrial production (Table 55). In the base case the heat load is expected to be continuous and the harnessing level close to 100% of the potential. A remarkable share of heat is to be used by wastewater treatment plants. In the methane case, the cost of energy replacement stands for heat and power that has to be produced by other means. The value of replaced energy equals income from energy production in the base case.

Due to the high utilisation level of heat in the base case and the relatively high energy replacement cost in the methane case, the difference between the cases is merely moderate. In the methane case, the sludge treatment cost de creases in the Turku and Salo regions by 7 €/t and the net effect per capita is around 2 € less than in the base case. In Kymenlaakso the sludge treatment cost decreases by 8 €/t and the net effect per capita is around 18 € less than in the base case. The benefits of the methane case grow if one expects that in the base case the vastly available heat is used ineffectively and not all of it is actually needed at the wastewater treatment plant. If the heat load is expected to be only 1/3, the difference between the cases grows to 13-14 €/t.

Table 52. Effects of biowaste treatment in the base case and methane case in the Kymenlaakso region.

KYMENLAAKSO REGION 2020 - Population 181 900		TREATMENT OF BIOWASTE			
BASE CASE		Waste incineration No source separation	Tunnel composting source separated	Bioethanol production source separated	Total amount of biowaste
Amount of biowaste	t/a	18 000	12 100	5 000	35 100
Energy production					
Energy content, LHV	MWh th	14 400	9 680	4 000	24 080
Heat, usability 33%	MWh th	3 148			3 148
Power	MWh el	2 733			2 733
Specific costs / incomes					
Waste treatment	€/t	-72	-80		
Waste transport	€/t	-65	-85		
Heat	€/MWh th	30			
Power	€/MWh el	45			
Profit (+) / loss (-)					
Cost of treatment	1000 €/a	-2 466	-1 997		-4 463
Income from energy production	1000 €/a	217			217
Total	1000 €/a	-2 249	-1 997		-4 245
	€/t biowaste	-125	-165		-121
Net effect per capita	€ / a	-12.4	-11.0		-23.3
METHANE CASE		Waste incineration No source separation	Biogas biomethane source separated		Total amount of biowaste
Amount of biowaste	t/a	6 200	18 200		24 400
Energy production					
Energy content, LHV	MWh th	4 960	14 560		19 520
Biomethane	MWh th		19 656		19 656
Heat, usability 33%	MWh th	1 084			1 084
Power	MWh el	941			941
Specific costs / incomes					
Waste treatment / Digestion	€/t	-72	-35		
Waste transport	€/t	-65	-35		
Upgrading	€/MWh th		-20		
Gas transport and refuelling	€/MWh th		-15		
Heat	€/MWh th	30			
Power	€/MWh el	45			
Biomethane	€/MWh th		100		
Profit (+) / loss (-)					
Cost of waste treatment	1000 €/a	-849	-1 962		-2 811
Cost of energy replacement	1000 €/a				-143
Income from energy production	1000 €/a	75	1 966		2 040
Total	1000 €/a	-775	4		-913
	€/t biowaste	-125	0		-37
Net effect per capita	€ / a	-4.3	0.0		-5.0

Table 53. Effects of sludge treatment in the base case and methane case in the Turku region.

TURKU REGION 2020 - Population 344 213	TREATMENT OF SLUDGE		
		BASE CASE	METHANE CASE
Amount of sludge	t/a	60 000	60 000
Power output	kW el / kW th	1 250	3 200
Energy production			
Biomethane	MWh th		25 200
Heat	MWh th	10 080	
Power	MWh el	10 080	
Specific costs / incomes			
Sludge treatment / Digestion	€/t	-40	-40
Sludge transport	€/t	-6	-6
CHP	€/MWh el	-25	
Upgrading	€/MWh th		-20
Gas transport and refuelling	€/MWh th		-15
Heat	€/MWh th	30	
Power	€/MWh el	45	
Biomethane	€/MWh th		100
Profit (+) / loss (-)			
Cost of treatment	1000 €/a	-3 012	-3 642
Cost of energy replacement	1000 €/a		-756
Income from energy production	1000 €/a	756	2 520
Total	1000 €/a	-2 256	-1 878
	€/t sludge	-38	-31
Net effect per capita	€ / a	-7	-5

Table 54. Effects of sludge treatment in the base case and methane case in the Salo region.

SALO REGION 2020 - Population 80 828	TREATMENT OF SLUDGE		
		BASE CASE	METHANE CASE
Amount of sludge	t/a	7 400	7 400
Power output	kW el / kW th	1 250	400
Energy production			
Biomethane	MWh th		3 110
Heat	MWh th	1 244	
Power	MWh el	1 244	
Specific costs / incomes			
Sludge treatment / Digestion	€/t	-40	-40
Sludge transport	€/t	-6	-6
CHP	€/MWh el	-25	
Upgrading	€/MWh th		-20
Gas transport and refuelling	€/MWh th		-15
Heat	€/MWh th	30	
Power	€/MWh el	45	
Biomethane	€/MWh th		100
Profit (+) / loss (-)			
Cost of treatment	1000 €/a	-372	-449
Cost of energy replacement	1000 €/a		-93
Income from energy production	1000 €/a	93	311
Total	1000 €/a	-278	-232
		-38	-31
Net effect per capita	€ / a	-3.4	-2.9

Table 55. Effects of sludge treatment in the base case and methane case in the Kymenlaakso region.

KYMENLAAKSO REGION 2020 - Population 181 900		TREATMENT OF SLUDGE	
		BASE CASE	METHANE CASE
Amount of sludge	t/a	206 000	155 000
Power output	kW el / kW th	1 250	8 100
Energy production			
Biomethane	MWh th		65 100
Heat	MWh th	26 040	
Power	MWh el	26 040	
Specific costs / incomes			
Sludge treatment / Digestion	€/t	-40	-40
Sludge transport	€/t	-6	-6
CHP	€/MWh el	-25	
Upgrading	€/MWh th		-20
Gas transport and refuelling	€/MWh th		-15
Heat	€/MWh th	30	
Power	€/MWh el	45	
Biomethane	€/MWh th		100
Profit (+) / loss (-)			
Cost of treatment	1000 €/a	-10 127	-9 409
Cost of energy replacement	1000 €/a		-1 953
Income from energy production	1000 €/a	1 953	6 510
Total	1000 €/a	-8 174	-4 852
	€/t sludge	-40	-31
Net effect per capita	€ / a	-45	-27

In the Turku region there are two landfills (Table 56). Due to the intensive placement of biodegradable waste to landfills in the past decade, gas will issue from them for a few more decades but the amount will decline gradually. Currently landfill gas from Topinoja is used for heating and gas from Isosuo is torched. However, the comparison is conducted with CHP production, since CHP would be the more profitable option in both cases than just using landfill gas for heating and torching. For economical upgrading, both of the landfills are too small. Thus the upgrading cost is counted as the combined cost with biogas production plants that are planned to be sited by the landfill areas. At both landfills, the net effect per capita is higher in the methane case, but the total effect remains minor due to the slight amount of gas that is generated at the landfills.

In the Salo region, there is one landfill in Korvenmäki. Yearly landfill gas production is about 1.3 GWh, which means that the power output of the upgrading plant would be only 160 kW th. Since none of biogas plants included in the biomass mapping were sited by the landfill, the scale of upgrading is uneconomical and relying on existing CHP production remains the more beneficial option.

In Kymenlaakso there are several landfills where landfill gas can be utilised for biomethane production (Table 57). The production potential of the municipal landfills at Keltakangas and Sammalsuo in Kouvola and at Heinsuo in Kotka is about 21 GWh/a. Industrial landfills, Sulento and Karhukangas, are located next to pulp and paper mills, and their potential is about 2.3 GWh/a. The bulk of the landfill gas is currently torched, with only 1.35 GWh being used for heating at the Heinsuo landfill. However, the comparison is conducted with CHP production, since CHP would be the more profitable option than torching or heating in all cases. For economical upgrading only the landfills at Keltakangas would be sufficiently large in scale (output power 1.4 MW_{th}). In biomass mapping, biogas plants are sited such that landfill gas can be utilised by other types of biogas production.

Effects in agriculture

The base case represents cereal farming and the methane case silage production, where cereal straw is also harvested for use in biomethane production. In the moderate growth path (1.5%), 500 hectares of fields in the Turku region and 10 hectares in the Kymenlaakso region are allocated to silage production instead of cereal farming. The straw harvesting areas in the Turku and Kymenlaakso regios would be 760 ha and 160 ha, respectively.

Table 56. Landfill gas in the Turku region

TURKU REGION 2020 - Population 344 213		LANDFILL GAS			
		BASE CASE		METHANE CASE	
		Topinoja	Isosuo	Topinoja	Isosuo
Amount of landfill rawgas	kNm3/a	14 000	200	14 000	200
Power output	kW el / kW th	350	60	900	160
Energy production					
Biomethane	MWh th			7 140	1 274
Heat	MWh th	2 856	510		
Power	MWh el	2 713	446		
Specific costs / incomes					
CHP	€/MWh el	-21	-55		
Upgrading	€/MWh th			-14	-16
Gas transport and refuelling	€/MWh th			-15	-15
Heat	€/MWh th	30	30		
Power	€/MWh el	45	45		
Biomethane	€/MWh th			100	100
Profit (+) / loss (-)					
Cost of energy production	1000 €/a	-57	-25	-207	-39
Cost of energy replacement	1000 €/a			-208	-35
Income from energy production	1000 €/a	208	35	714	127
Total	1000 €/a	151	11	299	53
Net effect per capita	€ / a	0.44	0.03	0.87	0.15

Table 57. Landfill gas in the Kymenlaakso region.

KYMENLAAKSO REGION 2020 - Population 181 900		LANDFILL GAS				
BASE CASE						
		Keltakangas	Sammalsuo	Heinsuo	Sulento	Karhukangas
Amount of landfill rawgas	GWh/a	11.2	3.1	6.5	1.5	0.8
Power output	kW el	532	147	309	71	38
Energy production						
Heat	MWh th	4 480	1 240	2 600	600	320
Power	MWh el	4 256	1 085	2 275	525	280
Specific costs / incomes						
CHP	€/MWh el	-15	-23	-17	-36	-57
Profit (+) / loss (-)						
Cost of energy production	1000 €/a	-62	-25	-39	-19	-16
Income from energy production	1000 €/a	326	86	180	42	22
Total	1000 €/a	264	61	142	23	6
Net effect per capita	€ / a	1.45	0.34	0.78	0.13	0.03
METHANE CASE						
		Keltakangas	Sammalsuo	Heinsuo	Sulento	Karhukangas
Amount of landfill rawgas	GWh/a	11.2	3.1	6.5	1.5	0.8
Upgrading power output	kW el / kW th	1 400	388	813	188	100
Energy production						
Biomethane	MWh th	11 200	3 100	6 500	1 500	800
Specific costs / incomes						
Upgrading	€/MWh th	-16	-16	-16	-16	-16
Gas transport and refuelling	€/MWh th	-15	-15	-15	-15	-15
Profit (+) / loss (-)						
Cost of energy production	1000 €/a	-347	-96	-202	-47	-25
Cost of energy replacement	1000 €/a	-326	-86	-180	-42	-22
Income from energy production	1000 €/a	1 120	310	650	150	80
Total	1000 €/a	447	128	268	62	33
Net effect per capita	€ / a	2.46	0.70	1.47	0.34	0.18

In the fast growth path (10%) raw material inputs come largely from field production. Areas needed for meeting biomethane consumption are presented in Table 58.

The area that is allocated to biomethane silage production instead of cereal farming in the Turku region is 0.5% in the moderate growth path and 6.8% in the fast growth path and in Kymenlaakso it is 0.1% in the moderate growth path and 5.2% in the fast growth path of the total field area in the region. In the Salo region the area allocated to biomethane-silage production instead of cereal farming is 4.8% of the total field area in the region.

Net value of production in Tables 59, 60, 61, 62, 63 and 64 means the difference between production costs and the end value of the crop in the regional value adding chain. In the base case the end product is cereal, which is exported from the region as surplus product. In the methane case the end product is biomethane, which is consumed in the region. The net value of biomethane production is remarkably higher than the net value of cereal production. The net value of cereal production is negative, because income from production cannot compensate for the costs of production. In practice this means that a farmer cannot earn enough from the work to cover his or her expected salary and/or returns on his/her invested capital.

Table 58. Field areas needed for meeting biomethane consumption at a fast growth rate (10%).

	Turku region		Salo region		Kymenlaakso region	
	Silage	Straw	Silage	Straw	Silage	Straw
Needed field areas (ha)	750	10 200	4 000	6 050	5 000	7 600

Table 59. Income from agriculture in the Turku region.

TURKU REGION 2020		INCOME FROM AGRICULTURE	
		BASE CASE	METHANE CASE
Work performer / crop		€/ha	€/ha
Farmer, cereal/silage		65	137
Contractor, silage		-	453
Contractor, straw		-	129
Moderate growth path, 1.5 %	ha	1000 €/a	1000 €/a
Farmer, cereal/silage	500	32	68
Contractor, silage	500	-	226
Contractor, straw	760	-	98
Farmers' income		32	68
Contractors' income			324
Fast growth path, 10%	ha	1000 €/a	1000 €/a
Farmer, cereal/silage	6 750	438	923
Contractor, silage	6 750	-	3055
Contractor, straw	10 200	-	1313
Farmers' income		438	923
Contractors' income		-	4368

Table 60. Income from agriculture in the Salo region.

SALO REGION 2020		INCOME TO AGRICULTURE	
Work performer / crop		BASE CASE €/ha	METHANE CASE €/ha
Farmer, cereal/silage		65	137
Contractor, silage		-	453
Contractor, straw		-	129
Fast growth path, 10 %	ha	1000 €/a	1000 €/a
Farmer, cereal/silage	4 000	260	547
Contractor, silage	4 000	-	1810
Contractor, straw	6 050	-	779
Farmers income		260	547
Contractors income		-	2589

Table 61. Income from agriculture in Kymenlaakso.

KYMENLAKSO REGION 2020		INCOME FROM AGRICULTURE	
Work performer / crop		BASE CASE €/ha	METHANE CASE €/ha
Farmer, cereal/silage		65	137
Contractor, silage		-	453
Contractor, straw		-	129
Moderate growth path, 1.5%	ha	1000 €/a	1000 €/a
Farmer, cereal/silage	100	6	14
Contractor, silage	100	-	45
Contractor, straw	160	-	21
Farmers' income		6	14
Contractors' income			66
Fast growth path, 10%	ha	1000 €/a	1000 €/a
Farmer, cereal/silage	5 000	324	684
Contractor, silage	5 000	-	2263
Contractor, straw	7 600	-	978
Farmers' income		324	684
Contractors' income		-	3241

Table 62. Net value of the end products of crop production in the Turku region.

TURKU REGION 2020		NET VALUE OF END-PRODUCTS	
Crop		BASE CASE €/ha	METHANE CASE €/ha
Cereal		-74	
Silage, biomethane			542
Straw, biomethane			130
Moderate growth path, 1.5%	ha	1000 €/a	1000 €/a
Cereal production	500	-37	-
Silage production	500		271
Harvesting straw	760		98
		-37	369
Fast growth path, 10%	ha	1000 €/a	1000 €/a
Cereal production	6 750	-500	-
Silage production	6 750		3656
Harvesting straw	10 200		1322
		-500	4978

Table 63. Net value of the end products of crop production in the Salo region.

SALO REGION 2020		NET VALUE OF END-PRODUCTS	
Crop		BASE CASE €/ha	METHANE CASE €/ha
Cereal		-74	-
Silage, biomethane		-	542
Straw, biomethane		-	130
Fast growth path, 10 %	ha	1000 €/a	1000 €/a
Cereal production	4 000	-296	-
Silage production	4 000	-	2166
Harvesting straw	6 050	-	784
		-296	2950

Table 64. Net value of the end products of crop production in Kymenlaakso.

KYMENLAKSO REGION 2020		NET VALUE OF END-PRODUCTS	
		BASE CASE	METHANE CASE
Crop		€/ha	€/ha
Cereal		-74	
Silage, biomethane			542
Straw, biomethane			130
Moderate growth path, 1.5%	ha	1000 €/a	1000 €/a
Cereal production	100	-7	-
Silage production	100		54
Harvesting straw	160		21
		-7	75
Fast growth path, 10%	ha	1000 €/a	1000 €/a
Cereal production	5 000	-370	-
Silage production	5 000		2708
Harvesting straw	7 600		985
		-370	3693

Employment

In the methane case in the Turku region the moderate growth path provides a total of 11% less work in biomass processing, transport and building. On the other hand, the fast growth path increases employment by about 84%, even though the amount of biowaste is expected to decline by a total of 30% from the base case situation. In the Salo region in the methane case the fast growth path increases employment by about 138%, mainly due to the harnessing of biomasses from agriculture. In the Kymenlaakso region in the methane case the moderate growth path results in about 56% and the fast growth path in 178% more work than the base case (Table 65).

The effect on employment in agriculture (Table 63) remains minor in all the case regions. However, remarkable changes involve who performs the work. In the methane case, to reach an efficient scale in silage production and straw harvest, fieldwork is largely performed by contractors.

Using manure in centralised biogas production does not make much difference to work in agriculture and is left out from the calculations. Manure simply leaves a farm and returns as digestate. Manure and digestate transport requirements are incorporated into the workload of biogas plants.

Table 65. Employment effects of the base case and methane case in the Turku region.

TURKU REGION 2020		EMPLOYMENT EFFECT				
BASE CASE		BIOWASTE		SLUDGE	TOTAL	
		Waste incineration No source separation	Biogas CHP Outsources treatment	Biogas CHP		
Amount of biomass	1000 t/a	39	8.3	60	107	
Specific employment factors						
Directatthe plants	Person / kt	0.17	-	0.05		
Transport	Person / kt	0.68	0.68	0.05		
Building phase	Person / kt	0.30	0.45	0.45		
Employment						
Directatthe plants	Person / a	7	-	3		
Transport	Person / a	26	6	3		
Building phase	Person / a	12	-	-		
Total employment	Person / a	34	6	6	45	
METHANE CASE		BIOWASTE AND SLUDGE		AGRICULTURAL BIOMASS		TOTAL
		Waste incineration No source separation	Biogas biomethane	Biogas biomethane Moderate growth 1.5 %	Biogas biomethane Fast growth 10 %	
Amount of biomass	1000 t/a	9.2	86	5	320	
Specific employment factors						
Directatthe plants	Person / kt	0.17	0.06	0.06	0.06	
Transport	Person / kt	0.68	0.27	0.04	0.04	
Building phase	Person / kt	0.30	0.45	0.45	0.45	
Employment						
Directatthe plants	Person / a	2	6	0.3	21	
Transport	Person / a	6	24	0.2	13	
Building phase	Person / a	3	39	2	144	
Total employment						
Moderate growth, 1,5 %	Person / a	8	32	1		40
Fast growth, 10 %	Person / a	8	32		43	83

Table 66. Employment effects of the base case and methane case in agriculture in the Turku region.

TURKU REGION 2020	EMPLOYMENT EFFECT IN AGRICULTURE		
Work norms	Field work h/ha	Transport h/ha	Total h/ha
Cereal production	7.3	0.7	8.0
Silage production	5.0	2.6	7.6
Harvesting straw	0.7	0.5	1.2
	ha	BASE CASE Persons / a	METHANE CASE Persons / a
Moderate growth path, 1.5%			
Cereal production	500	2	-
Silage production	500	-	2
Harvesting straw	760	-	1
		2	3
Fast growth path, 10%			
Cereal production	6 750	30	-
Silage production	6 750	-	28
Harvesting straw	10 200	-	7
		30	35

Table 67. Employment effects of the base case and methane case in the Salo region.

SALO REGION 2020		EMPLOYMENT EFFECT			
BASE CASE		BIOWASTE		SLUDGE	TOTAL
		Waste incineration No source separation	Biogas CHP Outsources treatment	Biogas CHP	
Amount of biomass	1000 t/a	11.3	3.8	7.4	23
Specific employment factors					
Directatthe plants	Person / kt	0.17	-	0.05	
Transport	Person / kt	0.68	0.68	0.05	
Building phase	Person / kt	0.30	0.45	0.45	
Employment					
Directatthe plants	Person / a	2	-	0.4	
Transport	Person / a	8	3	0.4	
Building phase	Person / a	3	-	-	
Total employment	Person / a	10	3	0.7	13
METHANE CASE		BIOWASTE AND SLUDGE		AGRICULTURAL BIOMASS	TOTAL
		Waste incineration No source separation	Biogas biomethane	Biogas biomethane Fast growth 10 %	
Amount of biomass	t/a	3.2	14.7	172	190
Specific employment factors					
Directatthe plants	Person / kt	0.17	0.06	0.06	
Transport	Person / kt	0.68	0.27	0.04	
Building phase	Person / kt	0.30	0.45	0.45	
Employment					
Directatthe plants	Person / a	1	1	11	13
Transport	Person / a	2	4	7	13
Building phase	Person / a	1	7	77	85
Total employment					
Fast growth, 10%	Person / a	3	5	23	31

Table 68. Employment effects of the base case and methane case on agriculture in the Salo region.

SALO REGION 2020	EMPLOYMENT EFFECT TO AGRICULTURE		
Work norms	Field work	Transport	Total
	h/ha	h/ha	h/ha
Cereal production	7.3	0.7	8.0
Silage production	5.0	2.6	7.6
Harvesting straw	0.7	0.5	1.2
		BASE CASE	METHANE CASE
	ha	Persons / a	Persons / a
Fast growth path, 10 %			
Cereal production	4 000	18	-
Silage production	4 000	-	17
Harvesting straw	6 050	-	4
		18	21

Table 69. Employment effects of the base case and methane case in the Kymenlaakso region.

KYMENLAKSO REGION 2020		EMPLOYMENT EFFECT				
BASE CASE		BIOWASTE		SLUDGE	TOTAL	
		Waste incineration No source separation	Tunnel composting source separated	Biogas CHP		
Amount of biomass	1000 t/a	18.0	12.1	206	236	
Specific employment factors						
Directatthe plants	Person / kt	0.17	0.15	0.05		
Transport	Person / kt	0.68	0.68	0.05		
Building phase	Person / kt	0.30	0.45	0.45		
Employment						
Directatthe plants	Person / a	3	2	10		
Transport	Person / a	12	8	10		
Building phase	Person / a	5	-	-		
Total employment	Person / a	16	10	20	46	
METHANE CASE		BIOWASTE AND SLUDGE		AGRICULTURAL BIOMASS		TOTAL
		Waste incineration No source separation	Biogas biomethane	Biogas biomethane Moderate growth 1.5 %	Biogas biomethane Fast growth 10 %	
Amount of biomass	1000 t/a	6.2	155	73	485	
Specific employment factors						
Directatthe plants	Person / kt	0.17	0.06	0.06	0.06	
Transport	Person / kt	0.68	0.27	0.04	0.04	
Building phase	Person / kt	0.30	0.45	0.45	0.45	
Employment						
Directatthe plants	Person / a	1	10	4.7	31	
Transport	Person / a	4	43	2.9	19	
Building phase	Person / a	2	70	33	218	
Total employment						
Moderate growth, 1.5%	Person / a	5	57	10		72
Fast growth, 10%	Person / a	5	57		65	128

Table 70. Employment effects in agriculture in the Kymenlaakso region.

KYMENLAKSO REGION 2020	EMPLOYMENT EFFECT IN AGRICULTURE		
Work norms	Field work h/ha	Transport h/ha	Total h/ha
Cereal production	7.3	0.7	8.0
Silage production	5.0	2.6	7.6
Harvesting straw	0.7	0.5	1.2
	ha	BASE CASE Persons / a	METHANE CASE Persons / a
Moderate growth path, 1.5%			
Cereal production	100	0	-
Silage production	100	-	0
Harvesting straw	160	-	0
Fast growth path, 10%			
Cereal production	5 000	22	-
Silage production	5 000	-	21
Harvesting straw	7 600	-	5
		22	26

5 Helsinki region

5.1 Potential biogas plants

The biogas plant locations were decided based mainly on the existing and planned biogas plants in the region. The Helsinki Region Environmental Services Authority (HSY) is planning to build a biogas plant in Ämmässuo and this was chosen as one location. Anaerobic digestion plants at the Viikinmäki wastewater treatment plant (WWTP) and the planned Blominmäki WWTP were also taken into consideration. Additionally, the location of an agricultural waste biogas plant was decided according to agricultural waste density and accessibility to the natural gas grid. The examined locations and the location of the planned waste incineration plant in the Helsinki region are presented in Figure 23.

HSY has decided to build a biogas plant but it is not yet clear how the capacity will develop. The overflow of biowaste (approximately 50%) will go to composting and bottom flow (approximately 50%) to digestion. The total calculated biowaste amount in 2020, taking into account waste prevention and more efficient source separation, is 120 000 t/a. This amount will be used in this study in the methane case 2020.

In the base case 2020 there is a biogas plant (80 000 t/a) in Ämmässuo and digestion is carried out at WWTPs in Viikinmäki and Blominmäki. The amount of masses in the base case and methane case 2020 and treatment methods are described in Table 71.Other plant sizes for the Ämmässuo waste treatment site are also estimated (80 000 t/a and 40 000 t/a) in a sensitivity analysis. Also the possibility of treating part of the biowaste at the Viikinmäki WWTP was considered. In Viikinmäki there is a possibility to increase treatment capacity for digestion by 10-20%. The amount of biowaste was defined by calculating 20% of the biomethane potential of the Viikinmäki WWTP and estimating how much biowaste would be needed to produce that amount of biomethane. This also means that the biowaste digestion plant in Ämmässuo would be smaller by this amount (13 000 t/a). The total amount of biomethane produced from biowaste would not change; only the locations and therefore the transport distances would be shorter. The biowaste amount treated in Ämmässuo would be 106 000 t/a. The biowaste was assumed to come from the four biowaste collection regions close to the Viikinmäki site.

On the basis of the above information, the sensitivity analysis examines a total of three different sizes of biogas plants at the Ämmässuo waste treatment site: 106 000 t/a, 80 000 t/a and 40 000 t/a. Additionally the anaerobic digestion of biowaste (13 000 t/a) and sludge at the Viikinmäki WWTP is included in the sensitivity analysis (Table 72).

The estimated source-separated biowaste amount seems quite high in relation to HSY's earlier estimates that the biogas plant should be capable of treating 80 kt/a. At the moment it seems that the composting facility is sufficient for treating all the household biowaste that HSY is obligated to treat. It seems that the biowaste from industry and retail is being increasingly channelled to other treatment facilities that are more competitive in treating biowaste.

At the moment the biogas from the Suomenoja WWTP is upgraded and it will be used in busses in the Helsinki region. The CHP facility at Suomenoja is old and its replacement would be costly. Since the Suomenoja plant will be closed, gas produced during its remaining time in operation will be directed to vehicle fuel use. Maybe this will also be the case in Viikinmäki once the CHP facility becomes old.

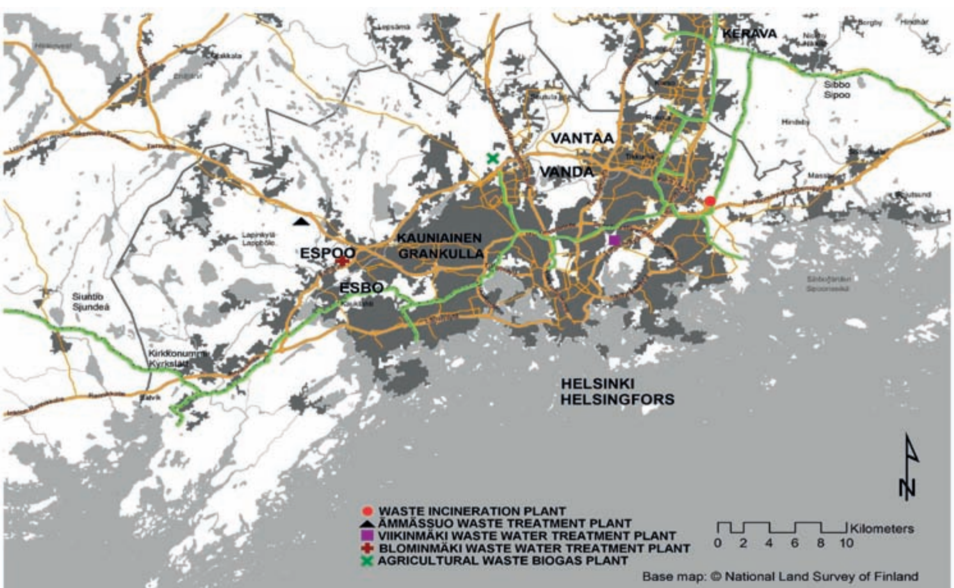

Figure 23. Examined biogas plants and waste incineration plant in the Helsinki region.

The digestate produced at the Ämmässuo site will be mechanically dewatered and composted in a tunnel composting facility located in Ämmässuo. The produced compost is sold to be used in soil amendment and landscaping. The reject water from mechanical dewatering goes to the wastewater treatment plant in Ämmässuo. Alternatively also evaporation and ammonia stripping can be used to treat the reject water. In addition, the digestate from sewage sludge digestion plants is composted and the compost is sold and the reject water goes to a wastewater treatment plant. The digestate from agricultural waste biogas plants is directed back to fields in order to utilise the nutrients.

Table 71. Scenarios and the use of produced and collected gas.

		Base case 2020		Methane case 2020	
		Mass	Gas use	Mass	Gas use
	Feedstock	t/a		t/a	
Ämmässuo digestion	Biowaste	80 000	Power&heat	120 000	Vehicle fuel
Ämmässuo composting	Biowaste	24 800		0	
Viikinmäki digestion	Sludge[1]	300 000	Power&heat	300 000	Vehicle fuel
Blominmäki digestion	Sludge[1]	135 000	Power&heat	135 000	Vehicle fuel
Agricultural biogas plant	Agricultural waste	-	-	108 000	Vehicle fuel

[1]Sewage sludge amount as total solids

Table 72. Biogas plants estimated in the sensitivity analysis.

			Sensitivity analysis	
			Mass (t/a)	Gas use
Ämmässuo	1	Digestion	106 379	Vehicle fuel
		Composting	0	
	2	Digestion	80 000	Vehicle fuel
		Composting	39 292	
	3	Digestion	40 000	Vehicle fuel
		Composting	79 292	
Viikinmäki digestion		Sludge1	29 883	Vehicle fuel
		Biowaste	12 913	Vehicle fuel

[1]Sewage sludge amount as total solids

Table 73. Results of the methane case 2020.

		Ämmässuo	Ämmässuo	Viikinmäki	Blominmäki	Agricult. Biomass
		Biowaste	MSW	Sludge	Sludge	
Waste amount	t/a	119 292				107 677
Total solids	%	27				40
Methane	MWh/a	115 951	105 120	62 755	28 311	112 106
Methane	m³/a	11 595 149	10 512 000	6 275 489	2 831 068	11 210 568
Biogas met	%	60	50	65	65	60
Biogas	m³/a	19 325 249	21 024 000	9 654 598	4 355 490	18 684 280
Digestate	t/a	119 292				107 677
Nitrogen	t/a	644				1 015
Phosphorus	t/a	129				193
El. Consumption	MWh/a	-4 921				-6 656
Heat consumption	MWh/a	-8 698				-11 765

Table 74. Results of the sensitivity analysis.

		1		2	3
		Ämmässuo	Viikinmäki	Ämmässuo	Ämmässuo
		106 kt	13 kt	80 kt	40 kt
Waste amount	t/a	106 379	12 913	80 000	40 000
Total solids	%	27	27	27	10 800
Methane	MWh/a	103 401	12 551	77 760	31 936
Methane	m³/a	10 340 052	1 255 098	7 776 000	3 193 603
Biogas met	%	60	60	60	60
Biogas	m³/a	17 233 419	2 091 830	12 960 000	5 322 672
Digestate	t/a	106 379	12 913	80 000	40 000
Nitrogen	t/a	574	70	432	216
Phosphorus	t/a	115	14	86	43
El. Consumption	MWh/a	-4 388	-533	-3 300	-2 100
Heat consumption	MWh/a	-7 756	-941	-5 833	-2 917

5.2 Economic and regional impact assessment

5.2.1 Consumption and capacity building of biomethane

In the Helsinki region, production potential can fulfil the consumption of about 6 500 vehicles. Figure 24 compares this potential to the relative growth in the number of methane vehicles in selected European countries. Relative growth stands for the number of methane vehicles divided by the number of vehicles that could achieve methane refuelling and the growth rates are compared to the number of vehicles in the Helsinki region.

The total production potential is 453 GWh_{th}, which corresponds to about 4.1% of the fuel consumption of vehicles in the region. The results are expressed in two different development paths, where the moderate growth rate represents 1.5% of the vehicle stock transferred to methane-fuelled vehicles within a 10-year period. Fast growth represents usage of total potential, which means 4.1% transfer. Biomethane production capacity is expected to be built in step with growth in regional consumption (Figure 25).

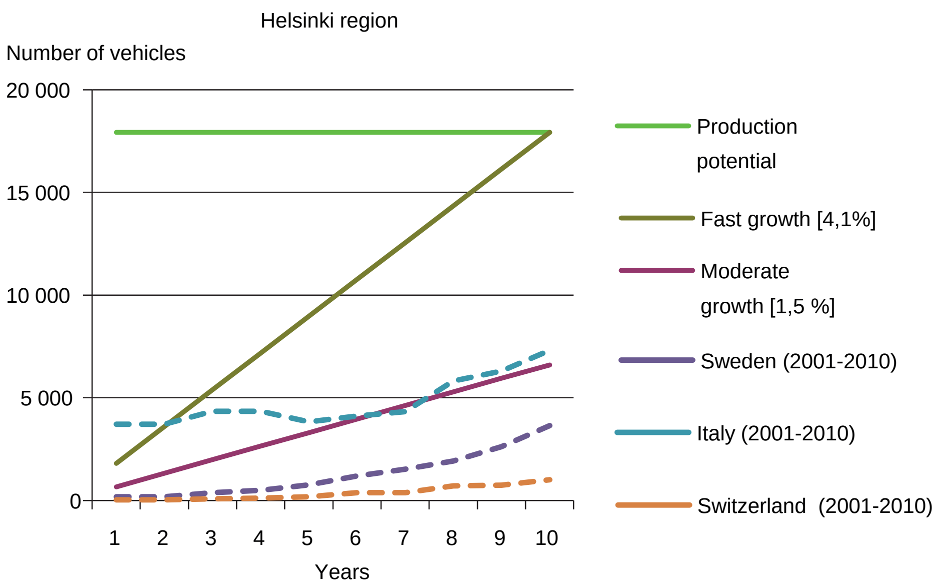

Figure 24. Growth rate path of methane-driven vehicles in the Helsinki region compared to relative growth in the number of methane vehicles in selected countries.

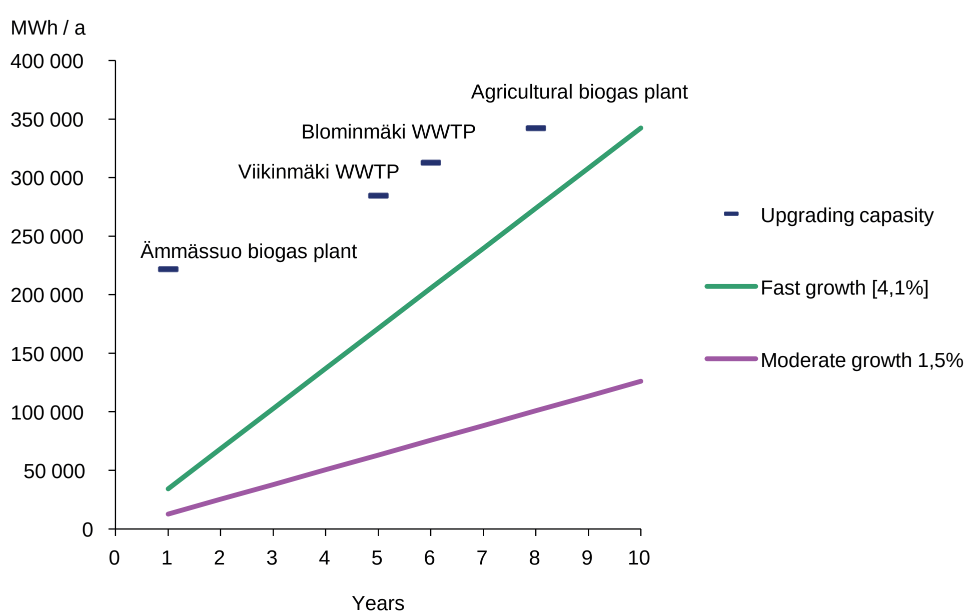

Figure 25. Growth paths of biomethane and the need to build new capacity to meet biomethane consumption in the Helsinki region.

It is notable that transfer in vehicle stock is counted as average consumption per vehicle. The most potential users of biomethane are public transport and waste trucks, whose consumption is about 3 times higher than that of average vehicles. Thus moderate growth would mean, for example, that all HSY city busses, 10% of other busses, all waste transport and 50% of taxis would be driven with biomethane. The fast growth path would require for example that all city busses, 30% of other busses, all waste transport, 50% of taxis and 3% of private passenger cars would change over to the use of methane fuel.

Table 75 expresses biomethane production units in order of profitability that are needed to meet consumption growth in the moderate and fast growth paths within a 10-year period. As it is known that the consumption of biomethane as a transport fuel will not directly reach the level of a single unit's production capacity, the cost of production is expressed for a 10-year transition period, where the production cost is an average, weighed with the amount of transport fuel biomethane produced each year. Thus, the full transport fuel consumption of a single plant's production capacity is expected to be achieved gradually, starting from 10% usage in the first year. The rest of the biomethane is expected to be fed to the natural gas grid at a producer price of 40 €/MWh th. The price of biomethane sold for use as transport fuel is expected to be 100 €/MWh.

It is notable that when the market has matured, at which point all biomethane can be sold as transport fuel, the production cost of biomethane will be about 6 €/MWh lower than presented in Table 75.

The production cost is highly dependent on the composition of the raw materials digested by the plants (Table 71). Biogas plants running with a high content of biowaste and sludge are remarkably profitable, with expected gate fees of 70 €/t biowaste and 30 €/t sludge. However, it can be presumed that gate fees will decline, even close to zero, and in a highly competitive situation will even turn negative. This obviously depends strongly on the development of the sector and the prospective support scheme for biomethane.

In Table 75, the cost of biomass means the transport and harvesting costs of field biomasses. Biogas production includes transport of other raw materials, as well as return freight and field spreading of digestate. Biomethane delivery includes the cost of the gas pipeline, gas grid connection, gas grid fee and refuelling.

5.2.2 Regional impacts

In the base case for the Helsinki region in the year 2020, there are landfill gas recovery facilities and a biowaste digestion plant at Ämmässuo, and anaerobic digestion is integrated into the wastewater treatment plants at Viikinmäki and Blominmäki.

In the base case the conversion efficiency from raw gas to electricity is 40% and to heat 40%, excluding the Ämmässuo landfill where the conversion efficiency to heat is only 32%. The operating efficiency of the gas boiler in Viikinmäki is 80% (Salmela 2011). In the base case the amount of biowaste will grow from 2010 to 2020. This additional biowaste in the mixed waste has to be transported to the Vantaa energy incineration plant. The electricity produced in the incineration plant from biowaste is sold to the grid and the heat is sold to district heating during three winter months.

5.3 Environmental impact assessment

As the Helsinki region already engages in biogas production and utilisation as well as has plans for a new biogas plant, the comparison of gas end use was made in the environmental impact assessment. The results are presented separately for each biogas production plant, as planned for the Helsinki region (Fig. 26).

Biomethane busses

The use of biomethane as a transport fuel causes emissions. CO_2 emissions are not taken into account, because they are bio-based, but CH_4 and N_2O are calculated.

Heat and electricity consumption

Heat and electricity consumption describes the extra heat and electricity used in every biogas production plant compared with the base case. Heat is produced by chip boilers and electricity by Finnish average electricity.

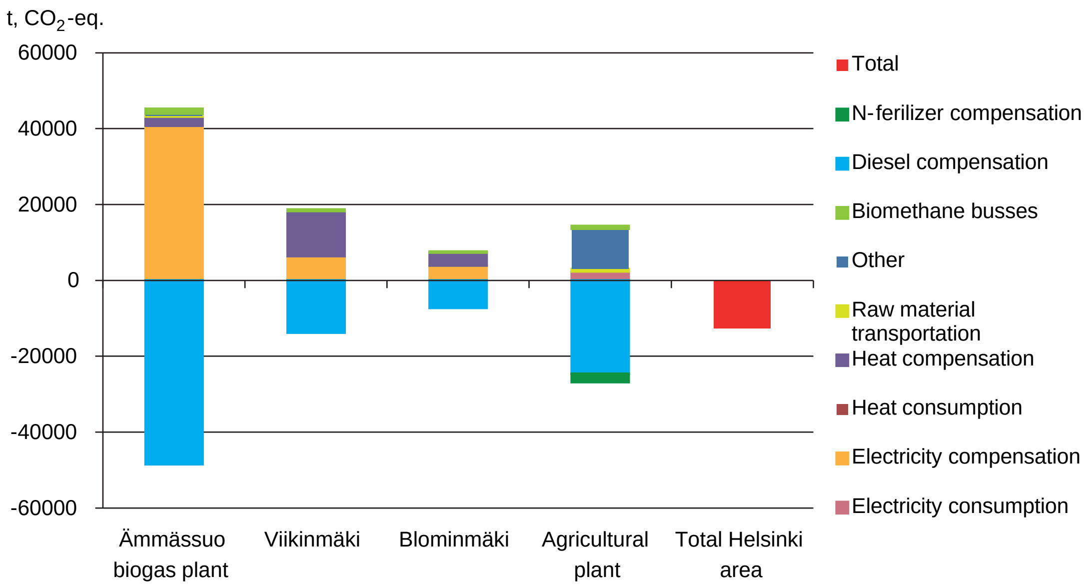

Figure 26. Comparison of emissions in the base case and methane case in the Helsinki region.

N fertiliser compensation
The digested sludge from agricultural biogas plants is used as soil amendment in fields, replacing mineral fertilisers and thus decreasing CO_2-equivalent emissions. Digested sludge from other plants is used as a raw material for different commercial soil products, and thus the emissions are not taken into account.

Heat and electricity compensation
In the base case, Viikinmäki and Blominmäki use the produced biogas in their own processes. In the methane case biogas is used as a transport fuel, and the plants have to use other energy sources. Heat is produced by natural gas boilers and electricity by Finnish average electricity.

Other
At the Ämmässuo, Viikinmäki and Blominmäki plants, the other emissions describe the emissions caused by the biogas upgrading process (methane leakage). At an agricultural plant, other emissions also include emissions caused by raw material procurement and digested sludge usage as soil amendment. The raw material procurement includes emissions from field biomass cultivation and harvesting, manure storage and biogas upgrading.

Diesel compensation
Diesel compensation describes the emissions that are compensated when biomethane is used as a transport fuel instead of fossil fuels.

5.4 Helsinki Region conclusion

Using biogas as a vehicle fuel instead of energy production in the Helsinki region would result in emission reductions (13 000 $t_{CO2,eq}$/a). However if the fuel replacing biogas in energy production would be renewable, the emission reductions would be significantly greater. In the Helsinki region, wastewater treatment plants and the Ämmässuo waste treatment centre would instead most likely replace biogas with natural gas, according to HSY, which makes the change in biogas use undesirable.

The economical assessment indicates that the production of biogas is economically feasible if all the produced gas can be sold. The total biomethane potential in the Helsinki region corresponds to approximately 450 GWh/a. The most potential user for biomethane is public transport. The total amount of biomethane would suffice for 80% of the busses operating in the Helsinki region. This would require the introduction of more gas-operated busses. Also taxis, passenger cars and waste trucks are potential users of biomethane. All the produced biomethane could be sold in the Helsinki region, which means that producing biomethane would be economically beneficial.

Biogas produced near the natural gas grid can also be transported to the Helsinki region where there are better possibilities to find uses for it. In this way, for example, gas that is produced in Kymeenlaakso but is not consumed there can be transported via the natural gas grid, assuming that the production plant is reasonably close to the grid.

6 Incentives for action

Waste prevention, biomethane production and use at the level planned in the prevention and methane cases in this study need to be enhanced by efficient incentives. These incentives can be legislative, administrative, economic and/or informative.

With governmental instruments, motivation is based on legal sanctions. Economic instruments give positive or negative incentives to achieving the desired development. Information instruments provide an impetus for positive change through advisory and educational work. In most cases, the best result is achieved by combining all these instruments. Important features of effective guidance are that it allocates effects correctly and that it is cost-effective and acceptable for the actors.

Correct allocation means that the "polluter pays" principle should be followed. Cost-efficiency requires that environmental benefits should be achieved with the lowest economic costs, and the running costs of the scheme are reasonable. Acceptability for the actors entails that the scheme is possible in the prevailing political environment, taking both political history and the power relations of peer groups into account. Payment transfers should be reasonable and the actors must be treated equally. Also, the economic situation has an effect on acceptability, whether it is a time of economic growth or depression.

Table 75. Capacity building order and costs of biomethane production in the Helsinki region.

HELSINKI REGION						
	Moderate growth 1.5%		Fast growth path 4.1%			
	Location	Ämmässuo	Vikinmäki	Blominmäki	Agricultural	Total / average
Capasity building order						
Moderate growth, 1.5% at 10 years	Year	1				
Fast growth, 4.1% at 10 years	year	1	5	6	8	
Production scale						
Upgrading output power	MW	27.7	7.8	3.5	3.7	42.8
Production potential, 100%	GWh th/a	222	63	28	30	342
Average transport fuel production, 55%	GWh th/a	122	35	16	16	188
Raw materials	1000 t/a	120	150	70	26	366
Biowaste	%	100				33
Sludge	%		100	100		60
Manure	%				4	0
Field biomass	%				96	7
Investment						
Biogas production	Mill. €	11.2	existing	4.3	4.2	19.7
Upgrading	Mill. €	4.4	3.1	1.8	1.7	11.0
Gas grid connection and refuelling	Mill. €	11.2	3.2	1.4	1.5	17.3
Total		26.8	6.3	7.6	7.4	48.0
Investment aid, 30%	Mill. €	8.0	1.9	2.3	2.2	14.4
Cost						
Biomass	Mill. €/a	-0.0	-0.0	-0.0	-0.4	-2.0
Biogas production	Mill. €/a	-8.3	-3.0	-1.3	-0.7	-16.2
Upgrading and delivery	Mill. €/a	-4.6	-1.3	-0.6	-0.7	-6.7
Total	Mill. €/a	-12.8	-4.3	-1.9	-1.8	-20.8
Income						
Gate fees	Mill. €/a	8.4	4.5	2.1	0.0	15.0
Biomethane, transport fuel	Mill. €/a	12.2	3.5	1.6	1.6	18.8
Biomethane, other	Mill. €/a	4.0	1.1	0.5	0.5	6.2
Total	Mill. €/a	24.6	9.1	4.2	2.2	40.0
PROFIT (+) / LOSS (-)	Mill. €/a	11.76	4.82	2.25	0.32	19.15
Needed price of biomethane to cover costs of production						
With gate fees	€/MWh th	4	-40	-45	80	-2
Without gate fees	€/MWh th	72	91	90	80	78

6.1 Biowaste and sludge prevention

The results from the food waste prevention impact assessment show that food waste prevention is a more effective method of decreasing the emissions caused during the life cycle of food compared to different waste management alternatives. Environmental and economic savings can be achieved by waste prevention that encourages using a comprehensive set of state- and municipal-level incentives targeting administration, companies, organisations and households.

6.1.1 Legislative and economic

In order to achieve prevention, targets should be set. Incorporating measurable prevention targets into the Waste Act is the basic requirement for progress. To gather and deliver data on waste and sludge, a new waste data bank could be established. The existing waste benchmark system used in the Helsinki region could be developed into a state-wide waste and sludge data bank. All large-scale waste producers could be obligated to keep records of their wastes and their prevention and treatment of wastes and to feed this data into the waste data bank. The waste fees should be set on the basis of actual volumes to ensure more effective waste prevention and separate collection of biowaste.

Few legislative measures have been instituted to prevent sludge. That said, the use of harmful scents and colours in detergents should be banned in order to decrease the harmfulness of sludge phosphate. The minimum levels of company wastewater fees and the criteria for company wastewater fees are decided by the state, and thus this fee could take into account the prevention of harmful substances.

6.1.2 Informative

Promoting waste prevention is more effective when the environmental and economic effects of waste prevention are shown. There should be more research on waste prevention to show the environmental and economic benefits to waste producers, municipalities and the national economy. Research on waste prevention and its development should be promoted.

Advisory services for waste and sludge prevention and the related resources (gathered e.g. in waste and wastewater fees) could be centralised at regional advisory centres, which promote material and energy efficiency and sustainable water management among consumers, companies and institutions. Production of advisory materials on waste and sludge prevention could be concentrated at the state level at the centre for material efficiency, which in Finland is run by Motiva Ltd[10]. This company could gather and update the biowaste prevention materials for consumers, retail and public food services. Advisory services for waste and sludge prevention should also include campaigns on degreasing harmful substances and pharmaceutical materials in wastewaters. For instance, the materials of Svenskt Vatten on the prevention of harmful substances (Svenskt Vatten 2011a, 2011b, 2009) could be used.

6.2 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.

6.2.1 Governmental instruments

EU's directive (2003/30/EC) on the promotion of the use of biofuels for transport represents existing governmental guidance[11]. 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 biogas. Municipalities can use environmental criteria when purchasing vehicles or transportation services. According to law (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,

10 State-owned expert company promoting efficient and sustainable use of energy and materials.

11 The biofuel supply requirement in Finland is 6% in the years 2011-2014 and 20% in the year 2020.

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 biowastes 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.

6.2.2 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 biogas 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 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.

7 Conclusions

In total 3 TWh energy could be produced from available biomass in studied case regions. From biogas plants, planned in this study, biomethane production covers from 5 to 40 % of passenger car fuel consumption in case regions. Locally produced biofuel would reduce especially traffic based GHG emissions by 450 000 t CO_2-eq and would increase the employment. In the Turku, Salo and Kymenlaakso regions, silage and other agricultural materials account from 94 to 98% of the total theoretical biogas potential. The Helsinki region waste materials represent 65% of the biogas potential.

Biomethane production from waste materials is profitable. Producing biomethane in large scale from e.g. agricultural materials would need support instruments so that the biomethane demand becomes established. After that biomethane production also from agricultural materials is profitable. For example, the decision to change the cities local transportation for biomethane fuelled vehicles would give a starting point for biomethane producers. Also a tariff bases support system bind for example to oil price should be considered.

The results of this study also show that achieving the food waste prevention target (30% decrease from 2009 amounts by 2020) will decrease greenhouse gas emissions by 415 000 CO_2-eq tons and result in monetary savings for the waste generators amounting to almost 300 €/capita on average in all case regions in 2020. The results show that waste prevention should be the first priority in waste management and the use of waste materials as feedstock for energy production the second priority.

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