Potential of energy and nutrient recovery from biodegradable waste by co-treatment in Lithuania

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Abstract: Biodegradable waste quantities in Lithuania and their potential for the co-treatment in renewable energy and organic fertilizer production are investigated. Two scenarios are formulated to study the differences of the amounts of obtainable energy and fertilizers between different ways of utilization. In the first scenario, only digestion is used, and in the second scenario, other materials than straw are digested, and straw and the solid fraction of sewage sludge digestate are combusted. As a result, the amounts of heat and electricity, as well as the fertilizer amounts in the counties are obtained for both scenarios. Based on this study, the share of renewable energy in Lithuania could be doubled by the co-treatment of different biodegradable materials.

Keywords: energy recovery, nutrient recovery, anaerobic digestion; biodegradable waste; Lithuania; digestate; renewable energy; co-treatment

Introduction

Currently, new EU member states and countries surrounding the EU are restructuring their environmental protection systems and implementing the best available environmental technologies. Waste management, especially biodegradable waste management, is one of the main target fields in this process.

The utilization of biodegradable waste is driven by the need to reduce greenhouse gases (GHG) and to improve the efficient use of natural resources. In Europe, the goal is that 20% of the total energy demand will be provided by renewable energy by 2020 (European Commission 2009), while currently 9% of the total consumption is renewable energy (Eurostat 2011). In addition, according to the EU landfill directive, the deposition of biodegradable municipal waste into landfills should be cut down to 50% of the amount deposited in 1995 by 2020 (European Commission 1999).

In Lithuania, the national strategic waste management plan aims at reducing the amount of biodegradable waste deposited into landfills from both households and industry to comply with 1999/31/EC. The target is that by 2013 the amount of biodegradable waste deposited at landfills will not exceed 50% of the amount deposited in the reference year 2000 (Ekokonsultacijos 2007, Lietuvos Respublikos Vyriausybės 2002).

The biomass energy potential in Lithuania has been previously examined (Katinas et al. 2007, Katinas & Markevicius 2006, Katinas & Skema 2001). The renewable energy potential in Lithuania (Katinas et al. 2008, Streimikiene et al. 2005) and the ways to boost it (Silveira et al. 2006) have also been estimated. The studies indicate that wood and wood waste are the most potential biomasses for energy use. These studies focus mostly on the potential in the whole of Lithuania. The biogas potential from agricultural raw materials has been estimated previously (Navickas et al. 2009), as well as biodegradable waste amounts and problems in utilizing them (Juškaitė et al. 2007).

The lack of biodegradable waste management strategy is the most prominent problem according to Juškaitė et al. (2007). The different plans of regional waste management centers do not include industrial biowaste. This forces industrial plants to look for the utilization by themselves, thus increasing the costs. According to Finnish experiences, a co-treatment of municipal, industrial and agricultural biodegradable waste can regionally lead to economic and environmental benefits.

The aim of conducting this study is to add to the previous knowledge by investigating the different biodegradable waste materials from various sources and to examine the potential of renewable electricity, heat and organic fertilizers from co-treatment in Lithuanian counties. Also the possible CO_2 equivalent reductions are evaluated.

Materials and methods

The biodegradable waste amounts of ten Lithuanian counties were studied. Basic information about the counties is given in Table 1.

Table 1. Information on area and population of Lithuanian counties (Lithuanian statistics 2010).

County	Total land area km^2	Inhabitants	Population density inhb. km^{-2}	Agricultural area km^2
Alytus	5 400	180 000	33	1 400
Kaunas	8 100	670 000	83	3 800
Klaipėda	5 200	380 000	73	2 100
Marijampolė	4 500	180 000	41	2 600
Panevėžys	7 900	280 000	36	3 900
Šiauliai	8 500	350 000	41	4 600
Tauragė	4 400	130 000	29	2 100
Telšiai	4 400	170 000	40	1 900
Utena	7 200	170 000	24	2 000
Vilnius	9 700	850 000	87	2 400
Total	65 000	3 400 000	52	27 000

Note: Totals may not equal the sum of all components due to independent rounding.

Scenarios

The utilization of different biodegradable waste at present was examined, and two different scenarios aiming at producing renewable energy and organic fertilizers were formulated (Figure 1). The technologies applied in these two scenarios were digestion and digestion plus combustion.

In scenario 1, all biodegradable materials were assumed to be digested and the resulting digestate used as a fertilizer and biogas in CHP (combined heat and power) production. The digestate was assumed to be mechanically separated into solid (TS 20%) and liquid fractions.

In scenario 2, the sewage sludge was assumed to be digested separately from other materials, and the digestate separated into liquid and solid fractions. The solid fraction was assumed to be thermally dried with heat from biogas CHP production, and then combusted. Additionally, also the straw was assumed to be combusted. The ash was excluded from the fertilizer products, because it was assumed to be unsuitable for spreading on arable land. Other materials were assumed to be digested, and the digestate separated into liquid and solid fractions which could be used as fertilizers. All biogas was assumed to be utilized in CHP production.

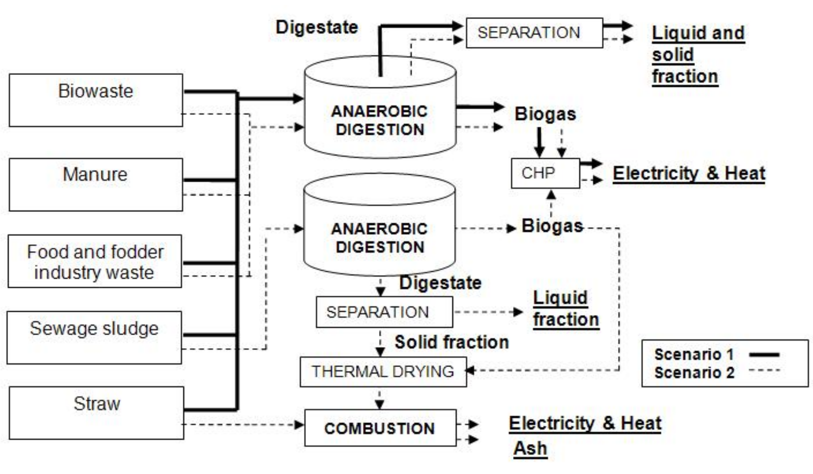

Figure 1. Description of scenarios 1 and 2.

Obtaining the biodegradable waste data

The biodegradable waste refers to manure, straw, sewage sludge, biowaste, slaughterhouse waste, fish residue, and other biodegradable waste from the food industry. Forest residues and waste from alcohol beverage industry and sugar industry, which is sold to farms to be used as fodder (Juškaitė et al. 2007), were excluded.

Manure from large farms without litter has good perspectives for biogas production. The amounts of manure in large non-littering cattle and pig farms and poultry farms have been evaluated by Navickas et al. (2009). Large farms refer to farms with 200 or above of livestock, 5000 or more pigs, and large poultry farms.

The potential of straw for energy production was calculated by using the arable land area covered by specific crops (Lithuanian Statistics 2010) and the potential of straw as total solids (TS) per hectare. The used straw yields were 2 t_{TS} ha^{-1} a^{-1} for oats and rape plant (Lehtomäki 2006), 2.3 t_{TS} ha^{-1} a^{-1} for rye (Kara 2004), 2.4 t_{TS} ha^{-1} a^{-1} for barley (Pahkala et al. 2007), and 3.8 t_{TS} ha^{-1} a^{-1} for wheat (Seibutis 2005). The proportion of straw that can be used for energy production has been estimated previously to be 10-15%, and the average of 13 % was used here (Bankinės konsultacijos 2008, Denafas et al. 2000, Katinas & Skema 2001).

The potential of biowaste was examined by evaluating the potential of separately collected biowaste from mixed municipal waste. The amounts of mixed municipal waste in the counties used were from the year 2004 (Denafas et al. 2006). The assumed proportion of biowaste in mixed municipal waste in the counties was 39% (Kaunas University of Technology 2009). It was assumed that it would be possible to collect 22% of the biowaste separately (Denafas et al. 2000).

Data on the other wastes were taken from previous studies. The amounts of sewage sludge in the counties in 2004 were obtained from a study conducted by the Lithuanian Environmental Protection Agency (Aplinkos Apsaugos Agentūra 2006). The amounts of food waste from industry were also from the year 2004 (Denafas et al. 2006). The figures for meat waste in the counties (Juškaitė et al. 2007) and other waste from the food industry (milk industry waste, waste from the crop industry and bakery waste) were obtained from the year 2005 (Staniškis et al. 2006).

The quantities of energy and organic fertilizers in the selected ways of utilization were calculated using Excel spreadsheets (Office Excel 2003, version number 11.0.8173.0) to form the mass balances for the examined techniques. The energy consumption of the utilization facilities themselves was included in energy product calculations.

The examined digestion technology was a wet (feedstock TS 15%) and mesophilic (35°C) process. The amounts of produced biogas and produced digestate were calculated using the data from Table 2. Biogas was assumed to contain 60% methane and 40% carbon dioxide (IE 2006, Steffen et al. 1998, Deublein & Steinhauser 2008). The biogas was assumed to be used in CHP production with 35% electrical efficiency and 50% thermal efficiency (Hoffmann et al. 2010). The total phosphorus and nitrogen amounts of the biomasses were supposed to remain the same during the anaerobic digestion in the digestate, but the amount of carbon was reduced because of the formation of carbon dioxide and methane.

Table 2. Properties of the biodegradable waste: total solids (TS), volatile solids (VS), biogas potential, carbon (C), nitrogen (N) and phosphorus (P).

Biomass	TS	VS	Biogas	Nutrients % TS			References
	%	%TS	$m^3n\ t_{VS}^{-1}$	C	N	P	
liquid cattle manure	10	80	380	45	5.5	0.9	1, 2, 3
liquid pig manure	3	78	480	30	11	3.0	1, 2, 3, 4
poultry manure	42	77	450	38	3.1	1.5	1, 2, 4
slaughterhouse waste	42	80	950	56	8.0	1.0	1
milk waste	13	65	700	45	5.0	1.0	1
fodder waste	27	86	660	47	3.4	0.6	1, 2, 3
straw	85	91	380	46	0.5	0.1	1
mill waste	88	95	500	45	2.5	1.1	1
biowaste	32	75	500	48	2.0	0.4	1, 2, 3
sewage sludge	11	69	450	35	4.0	2.5	1, 2

[1] Deublein & Steinhauser 2008 [2] Steffen et al. 1998 [3] IE 2006 [4] Sakar et al. 2009

The digestate was assumed to be mechanically separated into liquid and solid fractions with a centrifuge and used as a fertilizer in arable land. The separation enables the spreading of nutrients where they are needed most. The removal efficiencies into the solid fraction were 62% for the total solids, 26% for nitrogen and 73% for phosphorus, and total solid content of the solid fraction was 25% (Møller et al. 2002). The limit for applying nitrogen fertilizers to arable land is 80 kg ha^{-1} a^{-1} if the mineral nitrogen amount is within the depth of 0-60 cm more than 75 kg ha^{-1}, and otherwise 170 kg

ha^{-1} a^{-1} (Žemės ūkio ministerija 2005). For phosphorus the limit is 85-180 kg ha^{-1} a^{-1}, depending on the soil quality and rainfall in the region (Žemės ūkio ministerija 2005).

The electricity consumption of the processes consisted of electricity needed for digestion (15.3 kWh t^{-1}) (Börjesson & Berglund 2006) and for the mechanical separation of the digestate (4.5 kWh t^{-1}digestate) (Møller et al. 2002). The heat consumption included the heat required to warm up the feedstocks to the mesophilic temperature and heat losses from the reactor (Zupančič & Roš 2003).

The combustion of thermally dried sewage sludge digestate and straw was assumed to happen in CHP production with 22% electrical efficiency and 62% thermal efficiency (Bakos et al. 2008, BioPress 2005). The lower heating values used for dry material were 17.2 MJ kg^{-1} for straw (Alakangas 2000) and 10.5 MJ kg^{-1} for the sewage sludge digestate (Werther & Ogada 1999).

The produced electricity and heat reduced the GHG emissions by replacing the electricity and heat produced by fossil fuels. The total heat demand of Lithuania (10 TWh, Lithuanian Statistics 2010) was used to count the specific heat demand per person (3.1 MWh a^{-1} per person), and this number was used to determine the heat demand between the counties.

The produced heat was assumed to replace heat from a natural gas CHP plant with 35% electrical efficiency and 55% thermal efficiency. The calculated CO_2 equivalent emission factors for heat produced in a natural gas CHP plant were 230 kg MWh^{-1} for CO_2, 1.2 kg MWh^{-1} for N_2O and 0.25 kg MWh^{-1} for CH_4 (Lithuanian Ministry of Environment 2008). The produced electricity was assumed to replace the energy produced in a Lithuanian condensing power plant using natural gas with 40% electrical efficiency. The CO_2 equivalent emission factors for the electricity produced were 512 kg MWh^{-1} for CO_2, 2.7 kg MWh^{-1} for N_2O and 0.56 kg MWh^{-1} for CH_4 (Lithuanian Ministry of Environment 2008).

Additionally, GHG reductions were obtained by avoiding the deposition of biowaste and sewage sludge in landfills and by replacing mineral fertilizers. The used methane potentials from depositing the waste into landfills were 147 m^3 t_{TS}^{-1} for biowaste (Christensen et al. 1996) and 106 m^3 t_{TS}^{-1} for sewage sludge (Jeon et al. 2007). The methane from landfill was assumed to enter the atmosphere. The emission factors for producing mineral fertilizers were 8.9 $kg_{CO2,eq}$ kg_N^{-1} and 1.8 $kg_{CO2,eq}$ kg_N^{-1}. The potential amount of new nutrients, replacing fossil nutrients, is the amount of nutrients in biowaste and sewage sludge digestate because the nutrients in straw and manure are already to date going to arable land. In scenario 2, when straw is combusted, nutrients were assumed not to go to arable land. The nutrient amount of straw has to be replaced and therefore the potential amount of new nutrients in scenario 2 is smaller than in scenario 1. The unburned methane from biogas combustion caused the emission of 8.2 $kg_{CO2,eq}$ GJ^{-1} biogas. The GHG emissions from the collection and transportation were excluded because they do not produce much GHG emissions compared to GHG reductions by replacing fossil energy (Møller et al. 2009, Inaba et al. 2010, Zhao et al. 2009.)

Results

Present situation in the generation and recovery of biodegradable waste and production of energy

The most significant biodegradable waste examined was manure from non-littering large farms (65%), followed by sewage sludge (13%) and straw (11%) (Table 3).

Table 3. Biodegradable waste amounts in Lithuanian counties.

	Alytus kt a^{-1}	Kaunas kt a^{-1}	Klaipeda kt a^{-1}	Marijampole kt a^{-1}	Panevezys kt a^{-1}	Siauliai kt a^{-1}	Taurage kt a^{-1}	Telsiai kt a^{-1}	Utena kt a^{-1}	Vilnius kt a^{-1}	Total kt a^{-1}
Manure[a]	130	420	240	300	350	440	230	180	180	270	2 700
Meat waste	1	11	5	4	10	9	5	3	4	5	57
Milk waste	0	23	48	0	64	0	0	36	41	16	230
Fodder waste	0	0	0.3	0.3	0.1	0.1	0	0.2	0	0.3	1.3
Straw	15	82	18	69	90	120	20	18	15	28	480
Mill waste	1	4	2	2	4	5	1	1	0	2	22
Bakery waste	0.2	1.1	0.4	0.2	0.5	0.3	0.2	0.2	0.2	1.0	4.1
Biowaste	5	31	19	4	8	10	4	3	3	35	120
Sewage sludge	21	140	47	20	47	48	13	46	33	140	550
Total	170	710	380	400	570	630	270	290	270	500	4 200

[a] Manure from large non-littering cattle, pig and poultry farms

Note: Totals may not equal the sum of all components due to independent rounding.

There is currently a lack of biodegradable waste utilization in Lithuania. Biowaste is deposited into landfills, and most of the sewage sludge is stored. In 2007, almost half of the sewage sludge was stored in waste treatment sites, and one third was used as fertilizer in agriculture (Aplinkos Apsaugos Agentūra 2008). Most of the manure is applied to arable land, and there is only one biogas plant using manure in a pig farm (Katinas et al. 2008). Straw is left on the fields, or used as fodder or bedding (Katinas & Markevicius 2006). Food waste utilization varies a great deal depending on the production facility (Juškaitė et al. 2007).

Energy production was renewed after the closing down of the Ignalina nuclear power plant at the end of 2009.
According to the Lithuanian Ministry of Environment (2008), the share of the electricity produced in Ignalina is mainly replaced by the Lithuanian Thermal Power Plant which is a condensing power plant using natural gas.
In 2009, the total electricity consumption in Lithuania was 8.4 TWh, and the heat consumption 10 TWh (Lithuanian Statistics 2010). Approximately half of the heat is produced in CHP plants and half in heat-only boiler plants. The main fuels used in CHP and boiler plants are natural gas (13.9 TWh a^{-1}), wood (2.1 TWh a^{-1}) and heavy fuel oil (1.5 TWh a^{-1}) (Lithuanian Energy Institute 2008). Renewable energy composed 5% of the total electricity consumption and 15% of the total heat consumption in Lithuania in the year 2008 (Lietuvos Respublikos valstybės kontrolė 2010).

Results of scenarios 1 and 2

The biogas potential in scenario 1 was 1 700 GWh a^{-1}, which is 30 times more than the amount of biogas produced in the year 2009. The calculated amounts of electricity and heat in scenario 1 are presented in Table 4. The best possibilities of covering the county's heat demands were in Marijampole and Panevezys where 11% of the heat needed could have been covered with the heat from biogas CHP. The energy production in relation to the area from which the biodegradable wastes have to be transported for the utilization can be evaluated by energy density (MWh a^{-1} km^{-2}). The energy density was highest in Marijampole county.

Table 4. Energy and fertilizer products in scenario 1 and the district heat demand in Lithuania**.**

County	Elec. from biogas CHP GWh a^{-1}	Heat from biogas CHP GWh a^{-1}	Energy density MWh a^{-1} km^{-2}	Heat demand GWh a^{-1}	Solid fraction Mass kt a^{-1}	N kt a^{-1}	P kt a^{-1}	C kt a^{-1}	Liquid fraction Mass kt a^{-1}	N kt a^{-1}	P kt a^{-1}	C kt a^{-1}
Alytus	17	25	8	540	43	0.2	0.2	5	142	0.7	0.1	3
Kaunas	90	130	28	2 100	210	1.0	0.9	22	710	2.9	0.3	14
Klaipėda	36	52	17	1 200	82	0.6	0.4	9	280	1.6	0.2	5
Marijampolė	51	76	29	550	120	0.5	0.3	14	410	1.5	0.1	9
Panevėžys	79	120	25	870	180	0.8	0.5	20	610	2.3	0.2	12
Šiauliai	90	130	26	1 100	210	0.8	0.5	24	700	2.3	0.2	14
Tauragė	23	33	13	390	57	0.4	0.2	6	200	1.1	0.1	4
Telšiai	27	39	15	530	64	0.4	0.3	7	220	1.2	0.1	4
Utena	22	32	8	530	53	0.4	0.2	6	210	1.1	0.1	4
Vilnius	62	91	16	2 600	150	0.8	0.9	14	490	2.3	0.3	9
Total	500	730	19	10 000	1 200	6	4	130	4 000	17	2	78

Note: Totals may not equal the sum of all components due to independent rounding.

In scenario 2, 31% more electricity and 100% more heat was obtained because of the combustion of the solid fraction of sewage sludge and straw. The most significant amount of energy was obtained in Šiauliai County, as can be noticed from Table 5, but similarly to scenario 1, the best energy density was in Marijampole county. The heat produced in scenarios 1 and 2 would comprise 7% and 14%, and the produced electricity 6% and 8%, respectively, of the total energy consumption in Lithuania in 2009.

The mass of the solid fraction of the digestate in scenario 2 was 44% of the amount in scenario 1, but the mass of the liquid fraction was closer to the amount in scenario 1 (77%). The reason for this was that the straw contained less water than the other biodegradable wastes, and the water extracted from the sewage sludge digestate before combustion was included into the liquid fraction. In the liquid and solid fractions of digestate in scenario 2, there were 26% less phosphorus and 10% less nitrogen than in scenario 1. The difference in the amounts of nitrogen was smaller because the amounts of nitrogen in the combusted straw and the solid fraction of sewage sludge digestate were small compared to the nitrogen amount in other waste materials. The amounts of nitrogen in fertilizers could cover 5% of the total arable land in Lithuania, when applying the maximum allowed amount of nitrogen to arable land (170 kg ha^{-1} a^{-1}). The phosphorus concentration of the solid digestate fraction defines the applicable amount, of the solid digestate fraction, to arable land when the limit for phosphorus is lower than 125 kg ha^{-1} a^{-1}.

Table 5. Energy and fertilizer products in scenario 2.

County	Elec. [1]	Heat [1]	Energy density	Heat demand	Solid fraction Mass	N	P	C	Liquid fraction Mass	N	P	C	Ash Mass
	GWh a^{-1}	GWh a^{-1}	MWh a^{-1} km^{-2}	GWh a^{-1}	kt a^{-1}	kt a^{-1}	kt a^{-1}	kt a^{-1}	kt a^{-1}	kt a^{-1}	kt a^{-1}	kt a^{-1}	kt a^{-1}
Alytus	22	49	13	540	21	0,2	0,1	2	130	0,6	0,1	2	2
Kaunas	120	260	46	2 100	92	0,8	0,6	10	490	2,7	0,3	7	8,6
Klaipėda	42	79	23	1 200	50	0,5	0,3	6	280	1,6	0,1	4	2,7
Marijampolė	72	180	57	550	40	0,4	0,2	4	280	1,3	0,1	3	5,5
Panevėžys	110	250	46	870	64	0,7	0,4	7	390	2,0	0,2	5	7,5
Šiauliai	130	320	52	1 100	58	0,6	0,4	6	430	2,0	0,2	4	9,9
Tauragė	29	64	21	390	33	0,3	0,2	4	210	1,0	0,1	2	1,6
Telšiai	33	66	23	530	38	0,4	0,2	4	220	1,1	0,1	3	2,0
Utena	27	55	11	530	31	0,3	0,2	3	210	1,0	0,1	2	1,6
Vilnius	75	130	21	2 600	85	0,6	0,5	8	420	2,4	0,3	6	5,6
Total	650	1 500	32	10 000	510	5	3	54	3 000	16	1	37	47

Note: Totals may not equal the sum of all components due to independent rounding.
[1] From biogas CHP and combustion of solid fraction of sewage sludge digestate and straw

The calculated GHG reductions are presented in Figure 2 as CO_2 equivalent emissions. The GHG emission reduction from the renewable energy production in scenarios 1 and 2 corresponded to 6% and 10% of the total GHG emissions from the energy production in Lithuania in 2007 (6 500 $kt_{CO2,eq}$), respectively (Lithuanian Ministry of Environment 2008). The reduction of the deposition into the landfills was the same in both scenarios since the same amount of biodegradable waste deposition into the landfills was avoided. This reduction was equivalent to 11% of the GHG emissions from the depositing of MSW (municipal solid waste) in Lithuania in 2007.

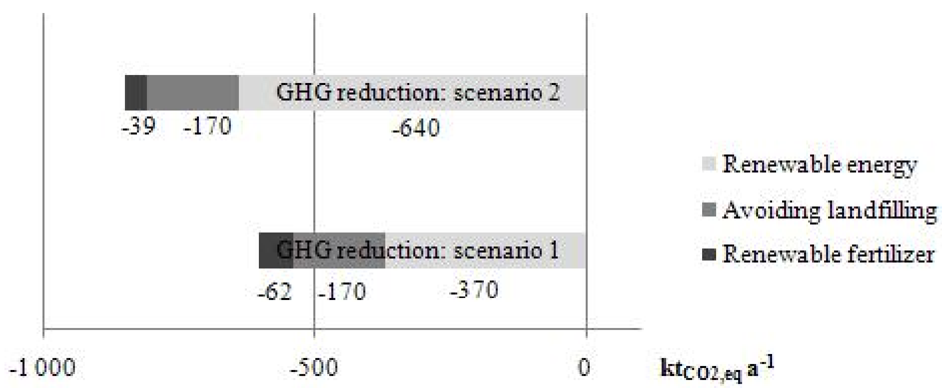

Figure 2. Calculated contribution to decreased GHG emissions in scenarios 1 and 2.

Sensitivity analysis

The amounts of obtainable biodegradable waste from households and farms can vary, depending on the economics of collection and on the farms' desire for utilizing their biodegradable waste. When the biowaste collection rate was decreased from 22% to 0%, the amount of energy was 5% and 3% less and the quantity of the organic fertilizer was 3% and 4% lower in scenarios 1 and 2, respectively. On the other hand, doubling the biowaste collection rate from the assumed 22% to 44% increased the amounts of end products with equivalent percentages (increase 3% and 5% in energy and 3 and 4% in organic fertilizers).

In scenario 1, increasing the proportion of straw available for energy production from the above mentioned 13 % to 20% increased the energy production by 27%, and decreasing it to 6% similarly decreased the energy production by 27%. In scenario 2, a similar change in the proportion of straw available caused the energy production to increase and decrease by 38%. Wet digestate amounts increased or decreased by 25% and 22%, respectively, in scenario 1. There was no change in the fertilizer amounts in the solid and liquid fractions of digestate in scenario 2 because all of the straw goes to combustion.

Discussion

The obtained biodegradable waste amounts show that there is a potential feedstock which could be utilized better in co-treatment to generate energy and organic fertilizers. The reason why these waste amounts have not been utilized so far is that the spreading of raw manure and straw to arable land is a cheap and easy way to dispose of them and to fertilize the arable land. Also the low cost of disposal at landfills (Juškaitė et al. 2007) and the widely allowed storage of sewage sludge are affecting.

The calculated potential of biogas from manure (86 million m^3, 0.5 TWh a^{-1}) is in the same order of magnitude as the results presented in earlier studies: 0.52 TWh a^{-1} (Katinas & Skema 2001) and 0.43 TWh a^{-1} (Navickas et al. 2009). The total biogas potential (1.7 TWh a^{-1}) is greater than the previously evaluated 0.3 TWh a^{-1} (Katinas et al. 2007, Katinas & Markevicius 2006, Miskinis et al. 2006). Earlier studies do not, however, include straw in the biogas potential. The calculated biogas potential without straw is 0.9 TWh a^{-1}. Also a wider range, 0.2–5 TWh a^{-1} (Denafas et al. 2000), for biogas energy potential can be found in the literature. The energy potential of straw (1.8 TWh a^{-1}) is in the same order of magnitude as in previous studies (1.5 TWh a^{-1}) (Katinas et al. 2007, Katinas & Markevicius 2006, Miskinis et al. 2006).

When comparing the two scenarios, it is evident that more energy can be produced from straw when it is combusted. The amount of nutrients is only slightly lower due to the low amounts of nutrients in straw. Straw is, however, a difficult fuel when combusted alone because of its K^+ and Cl^- contents. Straw should be combusted with other biofuels rather than with MSW, so that the produced electricity would be considered as renewable energy, and thus purchasing it would be promoted according to Lithuanian law. The sewage sludge should be incinerated in a few places only because of the high costs of building a waste incineration plant. The renewable energy from scenarios 1 and 2 would have raised the share of renewable energy to 11-13% of the electricity consumption and 22-29% of the heat consumption in Lithuania in 2008. The biowaste collection rate did not affect the obtainable energy amounts as much as the proportion of straw available for energy production. This was due to the fact that the amounts of straw far exceed the amount of obtainable biowaste.

The utilization of biodegradable waste also allows for the generation of organic fertilizers which can be used to replace inorganic fertilizers. The application of sewage sludge digestate to arable land requires an examination of the quality and amounts of heavy metals. The separation of the digestate to phosphorus rich and nitrogen rich fractions may, in some counties, be needed to follow the rules for nutrient application to arable land. The generated heat could also be used in refining the fertilizer products by thermal drying of the digestate and making the concentrated fertilizer liquid.

Most of the revenue of the biogas plants usually comes from the gate fees for waste. This would require landfill disposal to become expensive enough to make it economically reasonable to bring the waste to such facilities. At the moment landfill gate fees in Lithuania cover the transport and collection costs but the construction, maintenance and closing of landfills is financed by municipalities. If all the costs were included in calculating the landfill fee, the utilization would become more competitive. Landfill tax can also be used to direct waste away from landfill disposal. Creating working markets for the digestate would also help to make the utilization financially feasible.

In general, when examining the utilization of biodegradable waste, the amounts of biodegradable mass from one source are usually examined. These can be municipal, industrial or agricultural waste materials. However, it would be wiser to consider the utilization of these wastes together. In this way, we could have enough waste to allow the economical construction of utilization facilities compared to considering one waste fraction alone. This is evident from the specific investment information gathered from various Finnish and international sources for our research publication (Figure 3). The idea of co-treatment would also be helpful in forming the biodegradable waste management plan for Lithuania, the lack of which is the most significant hindering factor for the biodegradable waste utilization in Lithuania at the moment according to Juškaitė et al. (2007). For example, in Alytus county the capacity of a plant treating only biowaste would be 5 kt a^{-1}, but when taking into account other biodegradable waste, the treatment capacity could be over 100 kt a^{-1} which would significantly reduce the specific investment costs.

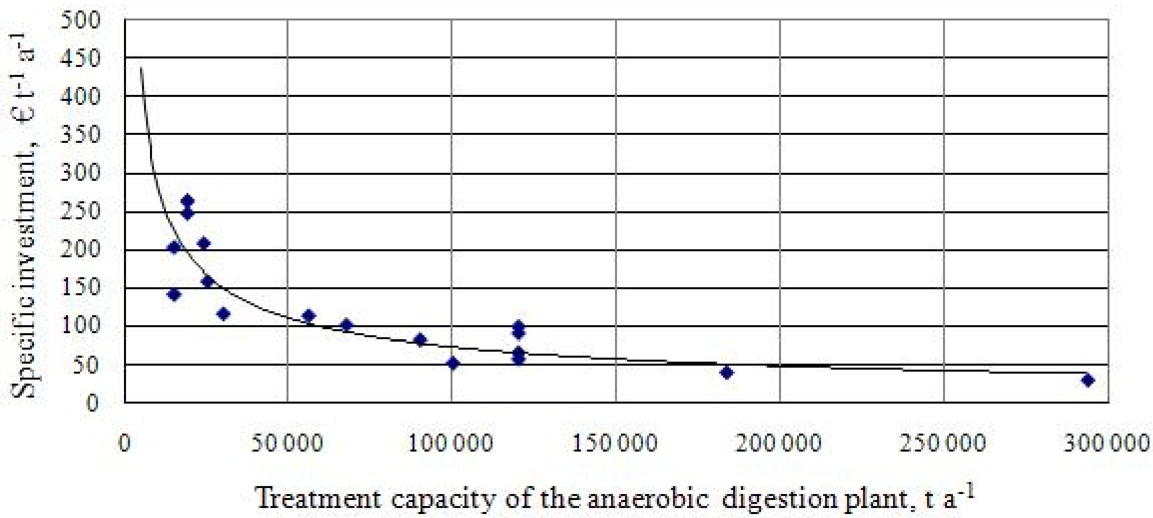

Figure 3. The specific investments of biogas plant (Kahiluoto & Kuisma 2010).

The location of biogas plant affects the possibilities for utilizing different wastes, as the transport distances for gathering some wastes may become too long. The usual location for a biogas plant is a waste water treatment plant or a waste treatment center, as these places already have waste that can be utilized. The co-treatment of wastes can also result in a better output of products. For example the co-digestion of wastes can increase the biogas output. If there are wastes which can contain harmful substances, such as sewage sludge, they can be digested in a separate reactor.

When the biodegradable wastes are co-treated in one facility, the use of the end products has to be considered more carefully. When building centralized utilization, there has to be a certainty of sufficient demand for the resulting energy and fertilizers. When producing heat and electricity, it is easier to sell the electricity. It can be fed into the grid, but the heat must be used locally. The heat demand should also be sufficiently great to be profitable in the summer when the heat demand is lower.

Conclusions

The share of renewable energy consumption could be doubled in Lithuania by the co-treatment of different biodegradable materials. The total amount of produced heat in scenarios 1 and 2 would have comprised 7% and 14%, respectively, and the produced electricity 6% and 8%, respectively, of the total heat and electricity need in Lithuania in 2009. The greatest potential for renewable electricity and heat from biodegradable waste would be in Šiauliai County: 130 GWh a^{-1} and 320 GWh a^{-1}, respectively. These energy amounts were obtained by combusting straw and digesting the other biodegradable waste fractions. Digestate has also a significant role because 5% of agricultural land could be fertilized with the digestate when calculated according to the maximum amount of nitrogen allowed on arable land.

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