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Tutkimusraportti Research Report 26

Jouni Havukainen, Mika Horttanainen
and Lassi Linnanen

Feasibility of ASH DEC- process in treating sewage sludge and manure ash in Finland

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Abstract

In Finland the thermal treatment of sewage sludge has been moderate in 21th century. The reason has been the high moisture content of sludge. During 2005-2008, 97-99% of sewage sludge was utilized in landscaping and agriculture. However agricultural use has been during 2005-2007 less than 3 %. The aim of national waste management plan is that by 2016 100% of sludge is used either as soil amendment or energy. The most popular utilization method for manure is spreading it on arable land. The dry manures such as poultry manure and horse manure could also be used in incineration. The ashes could be used as fertilizers and while it is not suitable as a starter fertilizer, it is suitable in maintaining P levels in the soil. One of the main drivers for more efficient nutrient management is the eutrophication in lakes and the Baltic See.

ASH DEC process can be used in concentrating phosphorus rich ashes while separating the heavy metals that could be included. ASH DEC process uses thermochemical treatment to produce renewable phosphate for fertilizer production. The process includes mixing of ashes and chlorine donors and subsequent treatment in rotary kiln for 20 min in temperature of 900 – 1 050 ^{o}C. The heavy metals evaporate and P-rich product is obtained. The toxic substances are retained in air pollution control system in form of mixed metal hydroxides.

The aim of conducting this study is to estimate the potential of ASH DEC process in treating phosphorus rich ashes in Finland. The masses considered in are sewage sludge, dry manure from horses, and poultry and liquid pig manure.

To date the usual treatment method for sewage sludge in Finland is composting or anaerobic digestion. Part of the amount of produced sewage sludge (800 kt/a fresh mass and 160 kt/a TS) could also be incinerated and the residual ashes used in ASH DEC process. Incinerating only manure can be economically difficult to manage because the incineration of manure is in Finland considered as waste incineration. Getting a permit for waste incineration is difficult and also small scale waste incineration is too expensive. The manure could act as an additional feedstock in counties with high density of animal husbandry where the land area might not be enough for spreading of manure. Now when the manure acts as a supplementary feedstock beside sludge, the ash can’t be used directly as fertilizer. Then it could be used in ASH DEC process. The perquisite is that the manure producers could pay for the incineration, which might prove problematic.

Table of contents

Abstract i
Table of contents iii
1. Introduction 1
2. Legislation 1
3. The potential masses 2
4. Drying of the masses 4
5. Incineration 5
6. The ash quality and utilization 5
7. ASH DEC process 9
8. Calculation 10
9. Scenarios 13
10. Results 14
   10.1. Total potential of sewage sludge and manure for incineration and ASH DEC 14
   10.2. Scenario 1 15
   10.3. Scenario 2 16
   10.4. Scenario 3 17
   10.5. Scenario 4 18
11. Discussion 19
12. Conclusions 21
References 22
Appendix 1. 26
Appendix 2. 27
Appendix 3. 28
Appendix 4. 29

1. Introduction

In Finland the thermal treatment of sewage sludge has been moderate in 21th century. The reason has been the high moisture content of sludge. During 2005-2008, 97-99% of sewage sludge was utilized in landscaping and agriculture. However agricultural use has been during 2005-2007 less than 3 %. The aim of national waste management plan is that by 2016 100% of sludge is used either as soil amendment or energy. (Ministry of the Environment 2012.)

In Europe the sewage sludge treatment includes also incinerating. The remaining ashes could be used in cement industry (Cyr et al. 2007) or road construction. The ashes can't be readily used in agriculture because of traces of heavy metals. Since phosphorus resources are becoming scarce also the removal of phosphorus from the ashes is becoming more interesting (Petzet et al. 2012, Wzorek et al. 2006, Adam et al. 2009, Franz 2008, Pettersson 2008a)

The most popular utilization method for manure is spreading it on arable land (Pöyry Environment 2007). The dry manures such as poultry manure and horse manure could also be used in incineration (Tyni et al. 2010, Lundgren & Pettersson 2009). The ashes could be used as fertilizers and while it is not suitable as a starter fertilizer, it is suitable in maintaining P levels in the soil (Kuligowski et al. 2010). One of the main drivers for more efficient nutrient management is the eutrophication in lakes and the Baltic See (Helcom 2007).

ASH DEC process can be used in concentrating phosphorus rich ashes while separating the heavy metals that could be included. The aim of conducting this study is to estimate the potential of ASH DEC process in treating phosphorus rich ashes in Finland.

2. Legislation

In this chapter is gathered some of the legislation concerning manure and sewage sludge incineration and ash use.

Waste treatment

- Regulation (EC) No 1069/2009 of the European Parliament and of the council laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation)

- Regulation of the Council of State on waste incineration 2003/362

Ash use as fertilizer:

- Regulation (EC) No 2003/2003 of the European parliament and of the council relating to fertilizers

- Fertilizer product act 539/2006

- Decree of the Ministry of Agriculture and Forestry on Fertilizer Products 24/11

- Decree of the Ministry of Agriculture and Forestry on the carrying out of activities related to fertilizer products and the control of fertilizer products 11/12

- Commission Decision (2006/348/EC) on the national provisions notified by the Republic of Finland under Article 95(4) of the EC Treaty concerning the maximum admissible content of cadmium in fertilizers

Suitability requirements of waste for landfilling

- Council of state regulation 202/2006 on changing the council of state decision on landfills

Suitability requirement for land construction

- Regulation of the Council of State on utilizing certain waste in land construction 591/2006

3. The potential masses

The masses considered in are sewage sludge, dry manure from horses, and poultry and liquid pig manure. Sewage sludge amounts from the finish counties are presented in Table 1.

The dry manure amounts were calculated from the poultry and horse amounts that were obtained for ELY centres (Centres for Economic Development, Transport and the Environment) (Tike 2011a). Poultry amount consists mainly from laying hens and broilers (85 %). In poultry husbandry 90.3 % (Tike 2011b) of the manure is collected as dry manure. The dry manure production per poultry animal per year was 0.05 t/animal/a and total solid (TS) content 38-50.1% (W-Fuel, Viljavuuspalvelu). Horse manure is entirely collected as dry manure. However horses are pasturing 5.5 months per year (Tike 2011c) during which time the manure ends up in fields. The manure production rate used for horses was 12.75 t/animal/a and TS content 32-33 % (W-Fuel, Viljavuuspalvelu). Manure amounts are presented in Table 2.

The amounts of pig manure were calculated similarly to horse and poultry manure. The amounts of liquid and dry pig manure include manure from hogs, sows, fattening pigs and piglets (Tike 2011d, W-Fuel). The amount of farms using only liquid manure systems is 49.6% and dry manure systems 18.1% (Tike 2011b). The farms using both systems simultaneously are excluded. The fur animal manure amounts include manure from female fur animals from the counties having more than 5 fur farms (Profur 2012, MMM-RMO C4,Viljavuuspalvelu).

Table 1. Sewage sludge amounts in finish counties.

County	**Sludge**			**Reference**
	t/a	t_{TS}/a	TS %	
Åland Islands	38 443	6 817	18	Avfallsstatistik 2010
South Karelia	13 212	2 510	19	EKJH 2010
Southern Ostrobothnia	37 101	6 676	18	Rytkönen 2012
Southern Savonia	16 000	3 400	21	Kahiluoto & Kuisma 2010
Kainuu	18 782	2 892	15	Turunen et al. 2008
Tavastia proper	18 777	4 080	22	Rytkönen 2012
Central Ostrobothnia	5 529	734	13	Rytkönen 2012
Central Finland	33 954	6 702	20	Yli-Kauppila et al. 2009
Kymenlaakso	30 086	5 716	19	W-Fuel
Lapland	73 000	14 600	20	Lapin ELY 2011
Pirkanmaa	69 200	15 100	22	Länsi-Suomen Ympäristökeskus 2009
Ostrobothnia	27 130	3 979	15	Rytkönen 2012
North Karelia	14 981	2 996	20	Pohjois-Karjalan ympäristökeskus 2009
Nothern Ostrobothnia	72 845	11 195	15	Turunen et al. 2008
Northern Savonia	56 739	11 348	20	Pohjois-Karjalan ympäristökeskus 2009
Päijänne Tavastia	24 200	5 372	22	Rytkönen 2012
Satakunta	64 000	11 000	17	Kahiluoto & Kuisma 2010
Uusimaa	117 000	30 400	26	Länsi-Suomen Ympäristökeskus 2009)
Finland Proper	68 400	13 680	20	Kahiluoto & Kuisma 2010,Länsi-Suomen Ympäristökeskus 2009
Total	**799 379**	**159 198**		

Table 2. Dry poultry and horse manure from ELY centres.

ELY centre	Poultry manure t/a	Horses manure t/a	Pig dry manure t/a	Pig liquid manure t/a	Fur animal manure t/a	Total t/a
Åland Islands	549	34 406	0	0	0	34 954
Southern Ostrobothnia	127 906	19 972	52 038	183 655	47 172	430 743
Southern Savonia	67 742	13 782	1 197	4 213	0	86 934
Häme	4 453	25 670	18 966	66 553	0	115 642
South Karelia	26 493	24 648	6 747	24 086	0	81 974
Kainuu	1 906	21 954	0	0	0	23 860
Central Finland	7 283	16 582	2 227	7 839	0	33 931
Lapland	822	20 615	0	0	0	21 438
Pirkanmaa	1 404	11 501	19 562	68 550	0	101 016
Ostrobothnia	2 247	21 355	49 156	174 011	127 480	374 249
North Karelia	72 624	22 412	1 159	4 080	0	100 275
Nothern Ostrobothnia	23 540	15 393	9 192	32 544	17 972	98 641
Northern Savonia	612	19 259	6 020	20 824	0	46 715
Satakunta	456	3 716	33 197	114 778	0	152 147
Uusimaa	208	5 257	6 352	22 577	0	34 395
Finland Proper	551	1 893	82 072	286 544	0	371 060
Total	338 796	278 415	287 885	1 010 254	192 624	2 107 975

4. Drying of the masses

The dry manure of poultry and horses do not require drying before the incineration but the sewage sludge has to be dried before incineration. The drying can be achieved for example by disc dryers, steam dryers or circulating fluidized bed dryer (Anttila et al 2008). The net energy consumptions used were 240 kWh/t_{H2O} for steam drier (used in min) and 669 kWh/t_{H2O} for disc dryer (used in max) (Hermann 2012). The TS content of sewage sludge after drying was assumed to be in min 80% and in max 95%.

The pig slurry is assumed to be mechanically dried with decanting centrifuge before it can be applied to thermal drying process. The removal efficiencies of the centrifuge are min 32.8% and max 62.1% for TS and min 60.4% and max 65.9% for P. The end product TS content is min 17.8% and max 27.9%. Energy consumption is min 4.3 kWh/t and max 6.0 kWh/t. (Møller et al. 2002.)

5. Incineration

In Finland sewage sludge and manure incineration is considered as waste incineration and requires waste incineration permit according to Waste Combustion Directive (WID) 2000/76/EC. Horse manure is considered as waste and the preferred use in legislation is fertilizer or soil conditioner use. In Sweden horse manure is considered as vegetable waste from agriculture and can be combusted without the requirements of WID (Edström et al. 2011). In Germany horse manure can be combusted as briquettes because it is then considered to be fuel.

Mono-incineration technologies for sewage sludge include: multiple heart furnaces, fluidized bed combustors (Lapa et al. 2007, Anttila et al. 2008), smelting furnaces, rotary kilns and cyclone furnaces (Werther & Ogada 1999). The horse manure can be used in heat producing boilers (Lundgren & Pettersson 2009, Tyni et al. 2010). Abelha et al. (2003) examined the combustion of poultry manure in fluidized bed combustor. Kelleher et al. (2002) state that both grate firing and fluidized bed firing can be used in poultry manure combustion. The assumed energy yields for fluidized bed incinerator with CHP production were in min 6% for electricity and 72% for heat (Horttanainen et al. 2010) and in max 14.5% for electricity and 74% for heat (Myllymaa et al. 2008).

6. The ash quality and utilization

Ash quality of poultry and horse manure ash is described in table 3, digested pig manure ash in table 4 and sewage sludge ash in table 5. Properties of fur animal ash were not available.

Table 3. Heavy metal concentrations of poultry and horse manure ash.

	Chicken litter ash Abelha 2003 µg/g	Horse manure Tyni et al. 2010	Horse manure + wood shaving Lundgren & Pettersson mg/kg_{TS}
Arsenic (As)		*	<3
Cadmium (Cd)	*	*	<0,1
Chrome (Cr)	112	*	1000 [1]
Copper (Cu)	71		105
Mercury (Hg)			<0,1
Nickel (Ni)	<LL	*	378 [1]
Lead (Pb)		*	5,4
Zinc (Zn)	209		344
Molybdenum (Mo)		*	10,3
Tin (Sn)			<20

* Under detection limit, LL = 10 µg/g, [1]contamination with stainless steel from furnace

Table 4. Heavy metal concentrations of pig manure ash from incineration and gasification (Kuligowski et al. 2008).

	Pig manure digestate Incineration mg/g	Pig manure digestate pellets Gasification mg/g
Cadmium (Cd)	95	47
Chrome (Cr)	84-552	158-178
Copper (Cu)	213-552	72-426
Nickel (Ni)	70	27
Zinc (Zn)	2087-3345	809-2247

Table 5. Heavy metal concentrations of sewage sludge ash.

	Swiss [1] mg/kg_{TS}	Germany & Netherlands [2] mg/kg_{TS}	Finnish[3] mg/kg_{TS}
Arsenic (As)	10,8 - 14,6	4,25 - 40	
Cadmium (Cd)	<0,4 - 1,9	2,23 - 4,71	
Chrome (Cr)	102 - 122	70 - 130	130
Copper (Cu)	417 - 625	470 - 1267	737
Mercury (Hg)		<0.1 - 0,23	1
Nickel (Ni)	49,6 - 92,5	39,5 - 80,2	46
Lead (Pb)	109 - 158	89,9 - 264	<175
Zinc (Zn)	910 - 1850	1540 - 2170	1228
Antimony (Sb)	3,9 - 29		
Molybdenum (Mo)		4,92 - 79,5	
Tin (Sn)		36,1 - 60	

[1]Franz 2008 [2]Adam et al. 2009 [3]Anttila et al. 2008

Ash from incinerating manure can be used as fertilizer on arable land or forest when the concentrations of harmful substances are low enough. The limits for harmful metals in fertilizers are given in Decree (24/11) and they are gathered to Table 6.

Table 6. Maximum concentrations of harmful metals in inorganic fertilizers and other fertilizer products (24/11).

	Max concentration mg/kg_{TS}	Forest fertilizer mg/kg_{TS}
Arsenic (As)	25	40
Mercury (Hg)	1	1
Cadmium (Cd)	1,5	25
Chrome (Cr)	300	300
Copper (Cu)	600	700
Lead (Pb)	100	150
Nickel (Ni)	100	150
Zinc (Zn)	1500	4500

The use of sewage sludge ash as fertilizer is currently not possible according to Decree 24/11. Only ash from combustion pure wood, peat or manure can be used as fertilizer (Evira 2008). Sewage sludge could be used in earth construction or in cement industry (Anttila et al. 2008). However, the possibility exists to change the EU legislation if good and pure fertilizer products are developed.

Use of waste incineration ashes in earth construction requires knowledge in the composition and quality changes. The waste incineration ashes require pretreatment to improve the suitability for earth construction (South-West Finland Environment Center 2009). The requirements of regulation 591/2006 for ashes from coal, peat, wood, bark or other wood based material are presented in Table 7.

Table 7. Limit of harmful substances in fly ashes and bottom ashes from combustion of coal, peat and wood based material for use in earth construction (Regulation 591/2006).

Harmful Substance	Limit value mg/kg_{TS} Basic characterizations			Limit value mg/kg_{TS} Quality control investigations		
	Content	Leaching (L/S 10 l/kg) Covered Structure	Paved Structure	Content	Leaching (L/S 10 l/kg) Covered Structure	Paved Structure
PCB	1,0					
PAH [1]	20/40					
DOC		500	500			
Antimony (Sb)		0,06	0,18			
Arsenic (As)	50	0,5	1,5	50		
Barium (Ba)	3 000	20	60	3 000		
Cadmium (Cd)	15	0,04	0,04	15		
Chrome (Cr)	400	0,5	3	400	0,5	3
Copper (Cu)	400	2	6	400		
Mercury (Hg)		0,01	0,01			
Lead (Pb)	300	0,5	1,5	300	0,5	1,5
Molybdenum (Mo)	50	0,5	6	50	0,5	6
Nickel (Ni)		0,4	1,2			
Vanadium (V)	400	2	3	400	2	3
Zinc (Zn)	2 000	4	12	2 000		
Selenium (Se)		0,1	0,5		0,1	0,5
Fluoride (F^-)		10	50		10	50
Sulphate (SO_4^{2-})		1 000	10 000		1 000	10 000
Chloride (Cl^-)		800	2 400		800	2 400

[1] Covered structure / paved structure

The sewage sludge ash can be disposed of into landfills if it meets the leaching requirements of Council of state regulation 202/2006 which are presented in Table 8.

Table 8. Leaching requirements for regular and hazardous waste disposal into landfill (Regulation 202/2006).

	Regular waste	Hazardous waste
	Leaching (L/S =10 l/kg)	
	mg/kg_{TS}	mg/kg_{TS}
Arsenic (As)	0,5	25
Barium (Ba)	20	300
Cadmium (Cd)	0,04	5
Chrome (Cr)	0,5	70
Copper (Cu)	2	100
Mercury (Hg)	0,01	2
Molybdenum (Mo)	0,5	30
Nickel (Ni)	0,4	40
Lead (Pb)	0,5	50
Antimony (Sb)	0,06	5
Selenium (Se)	0,1	7
Zinc (Zn)	4	200
Chloride (Cl-)	800	25 000
Fluoride (F-)	10	500
Sulphate (SO_4^{2-})	1000	50 000
Phenol-index	1	
Dissolved organic carbon (DOC)	500	1 000
Total dissolved solids (TDS)	400	100 000

VNa 202/2006 kaatopaikoista annetun valtioneuvoston päätöksen muuttamisesta

Disposing of the ashes into the landfills is expensive and not all the ashes can be used in earth construction and roads. The disposal of P-rich ash, such as sewage sludge ash, into the landfills or using them in earth construction is also not sustainable. One possible treatment is phosphorus recovery from the ash. The phosphorus can be recovered from the ash by leaching with acid (Petterson et al. 2008a, Petterson et al. 2008b, Wzorek et al. 2006), alkaline or acid and alkaline (Petzet et al. 2012). One other way to recover the phosphorus is the thermochemical removal of heavy metals from the ashes (Adam et al. 2007, Adam et al. 2009, Fraissler et al. 2009, Mattenberger et al. 2008, Vogel & Adam 2011) to produce P-fertilizer raw material. Thermochemical removal of heavy metals includes treatment of the ashes in temperature of 800 – 1000 ^{o}C with chlorine donors. The formed volatile heavy metal chlorides are then separated from the gaseous phase and consequently removed from the ash. The bioavailability of phosphorus is also increased by formation of new mineral phases. (Adam et al. 2009.)

The recovered phosphorus can be used in fertilizer production. The price of DAP (diammonium phosphate, $(NH_4)_2HPO_4$) has been changing between 434-691 USD between 5/2010-5/2012 and at the moment it is 558 USD/t (456 €/t) (Farmit 2012). DAP contains 18% N and 47% P_2O_5 (University of Minnesota 2012), which means that the P content is approximately 21%. The superphospate sold by Yara is called now days “phosphorus nutrient" (fosforiravinne). It contains 9% phosphorus. (Yara 2012.) At the moment it costs 580 €/t (Ylä-Uotila 2012).

7. ASH DEC process

ASH DEC process uses thermochemical treatment to produce renewable phosphate for fertilizer production. The process includes mixing of ashes and chlorine donors and subsequent treatment in rotary kiln for 20 min in temperature of 900 – 1 050 ^{o}C. The heavy metals evaporate and P-rich product is obtained. The toxic substances are retained in air pollution control system in form of mixed metal hydroxides. (ASH DEC 2009.)

The ASH DEC process consumes 118 kWh/t_{ash} electricity and 520 kWh/t t_{ash} heat as fuel energy (natural gas or biomass). If the ash to the process comes from the incineration fuel energy consumption is 50% of the normal need (260 kWh/t t_{ash} fuel energy). The requirement for the P_2O_5 concentration in the ash is more economical than technical issue. The expected concentration is at present 18 % P_2O_5 +/- 2%. Lower P_2O_5 concentration requires compensation by suitable P-carrier. There are no limitations for heavy metals when feedstock is composed of municipal sewage sludge ash, ash from manure or other P-rich materials. The process requires following additives: NaCl 46 kg/t_{ash}, MgO 39 t_{ash} and $NaHCO_3$ 49 kg/t_{ash}. (Hermann 2012.) The ASH DEC process with the needed pretreatment phases for the masses and incineration is presented in figure 1.

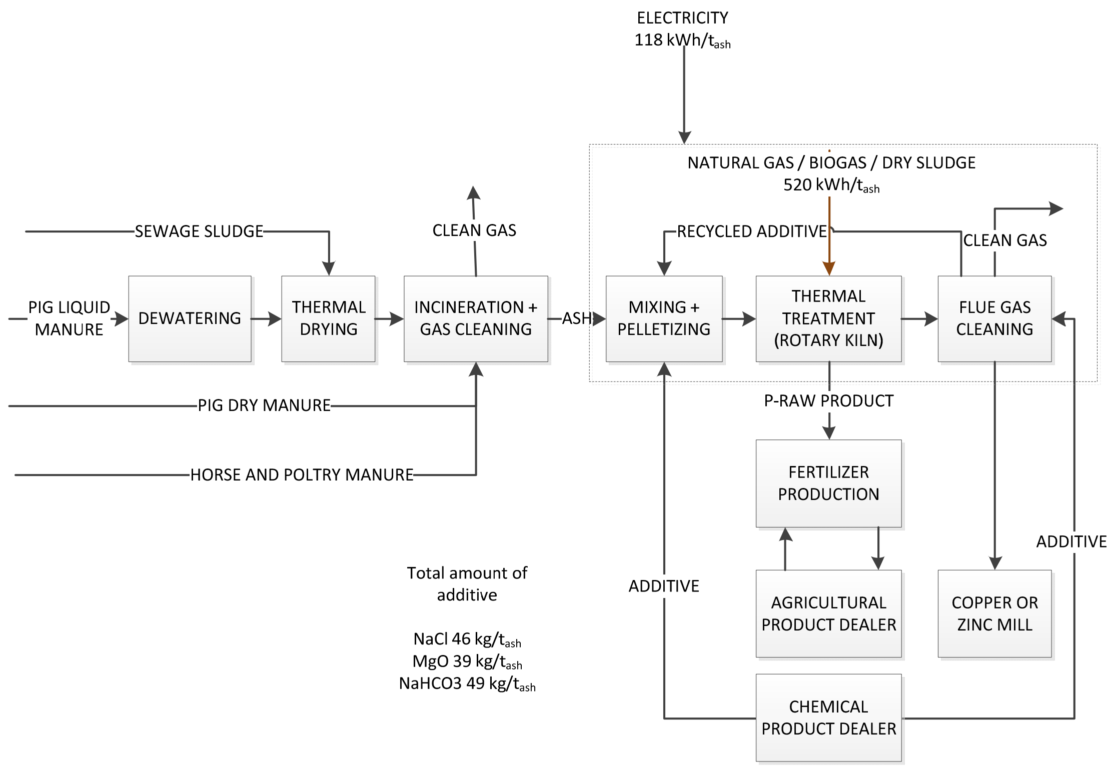

Figure 1. Pretreatment of masses, incineration and ASH DEC Process (ASH DEC 2009)

8. Calculation

The calculation was done using min and max values to create range for the results. The mass properties used in the calculations are presented in table 9 and the values used in calculating drying, incineration and ASH DEC process are presented in table 10.

Table 9. Properties of sewage sludge, horse manure and poultry manure.

	Min	Max	Reference
LHVdry (MJ/kg)			
Poultry manure	12,1	13,9	Quiroga et al. 2010
Horse manure	18,4	19,1	Lundgren & Pettersson 2009, Edström et al. 2011
Pig solid manure	12,8	13,4	Assume same as liquid manure
Pig liquid manure	12,8	15,2	Phyllis, Prapaspongsa et al. 2010
Fur animal	13	13	Assumed same as pig manure
Sewage sludge	15,3	20,7	Horttanainen et al. 2010, Anttila et al. 2008
TS (%)			
Poultry manure	38	50,1	W-Fuel, Viljavuuspalvelu
Horse manure	32	32,9	W-Fuel, Viljavuuspalvelu
Pig solid manure	25	54,9	Viljavuuspalvelu
Pig liquid manure	3,5	8	Prapaspongsa et al. 2010, Viljavuuspalvelu
Fur animal	38,5	38,5	Viljavuuspalvelu
Sewage sludge	table 1		
ASH content (% TS)			
Poultry manure	29,0	29	W-Fuel
Horse manure	40,0	40	W-Fuel
Pig solid manure	20,0	20	W-Fuel
Pig liquid manure	15,0	27	W-Fuel,Prapaspongsa et al. 2010
Fur animal	50,0	50	Wabio
Sewage sludge	16,0	20	Alakangas 2000, Lohiniva et al. 2001
P content (kg/tTS)			
Poultry manure	16,1	30,0	Viljavuuspalvelu
Horse manure	7,7	16,1	Viljavuuspalvelu
Pig solid manure	12,0	16,2	W-Fuel
Pig liquid manure	15,3	22,9	W-Fuel
Fur animal	41,6	71,5	Viljavuuspalvelu
Sewage sludge	25,0	25	W-Fuel

Table 10. Min and Max values used in the calculations.

	Min	Max	Unit	Reference
Mechanical drying				
TS separation efficiency	33	62	%	1
P separation efficiency	60	66	%	1
Electricity consumption	4,3	6,0	kWh/t	1
TS %	18	28	%	1
Thermal drying				
Heat consumption	240	669	kWh/t_{H2O}	2
TS%	80	95	%	2,3
Incineration CHP efficiency				
Electricity consumption	6,0	15	%	4,5
Heat consumption	72	74	%	4,5
ASH DEC				
Electricity consumption	118	118	kWh/t_{ash}	1
Fuel energy consumption	520	520	kWh/t_{ash}	1
NaCl consumption	46	46	kg/t_{ash}	1
MgO consumption	39	39	kg/t_{ash}	1
NaHCO3 (BICAR) consumption	49	49	kg/t_{ash}	1
End product yield	1,1	1,1	t/t_{ash}	1

1 Møller et al. 2002, 2 Hermann 2012, 3 Anttila et al. 2008, 4 Horttanainen et al. 2010, 5 Myllymaa et al. 2009

9. Scenarios

Three scenarios were formed to find differences in amounts of products, energy need and produced energy. In two first scenarios only sewage sludge is the feedstock for incineration. The main cities (capitals of the counties) in counties where the most sludge is produced are considered as possible plant locations, these are presented in appendix 1. The usual method to cheaply utilize manure is spreading on the fields and farms are reluctant to pay more for their utilization if disposal to fields is an option. Therefore, the manure was assumed to be feedstock in one scenario and in that scenario only small amount from the total potential of manure was considered as feedstock in areas where there is largest manure potentials.

Scenario 1

This scenario includes five incineration plants for sewage sludge one of which has an ASH DEC plant situated next to it that treats the ash from all the incineration plants. The incineration plants are CHP plants producing heat and electricity. Most of the heat from incineration is consumed by the thermal drying of sludge. The ASH DEC process uses dried sludge as a fuel. The plant locations are selected by looking into the available sludge amounts in counties and distances between the plant locations. The plant location with the ASH DEC plant should have the highest sludge amount and the other plants should be close to that plant location, in order to minimize transport distances.

Scenario 2.

In this scenario includes five sludge incineration plants which each have also ASH DEC plant close to it. As the plant locations are selected counties with high sludge amounts. They should also have a good sludge density (t/km^2) so that the transport distances inside the counties to the incineration do not become too long.

Scenario 3.

In the scenario 3 there is assumed to be five incineration plants with ASH DEC plant located next to it similarly to scenario 2. In this scenario also manure is used in some of the plants. The manure amounts coming to incineration are considered to be 10% of the total manure potential. The counties with highest end product potential from the feedstocks (sewage sludge + 10% from manure) are selected. Sludge is incinerated in CHP plant where also the drying takes place.

Scenario 4.

Scenario 4 includes two incineration plants one of which (plant 1), located in Uusimaa county, utilizes the sewage sludge and 25% of the manure from Uusimaa ELY centre area and three other ELY centre areas close to it. The other incineration plant (plant 2), located in Southern Ostrobothnia ELY centre area utilizes the sewage sludge and 25% manure from Southhern Ostrobothnia ELY centre area and from four other ELY centre areas around it. The liquid manure is assumed to be separated with mobile separation device going through the farms and the dewatered manure transported to incineration plant where the thermal drying takes place. The nitrogen in the slurry could also be separated to reduce the losses of nitrogen in different phases of manure storage (Lillunen & Yli-Renko 2011). The dry manure is going directly to the incineration. Sludge is thermally dried at incineration site. Both the incineration plants have an ASH DEC plant located in the vicinity.

10. Results

10.1. Total potential of sewage sludge and manure for incineration and ASH DEC

Total potentials of P raw product from ASH DEC process utilizing sewage sludge and manure ash in Finland are presented in table 11. The phosphorus share in P-raw product from sewage sludge ash is 14% in min and 13% in max. The phosphorus share in the total P-raw product produced from manure ashes changes, because of the varying shares of horse, poultry, pig and fur animal manures in counties. The phosphorus share in P-raw product from manure is 5-8% in min and 8-12% in max. The energy consumption and production from utilizing the total potential of sludge and manure are presented in appendix 2 and 3.

Table 11. Potential of P raw products from utilizing sewage sludge and manure ash in ASH DEC process in ELY centre areas.

	Sewage sludge P-raw product		Manure P-raw product		Total P-raw product	
	t/a Min	t/a Max	t/a Min	t/a Max	t/a Min	t/a Max
Åland Islands	1 212	1 515	4 960	5 119	6 172	6 634
Southern Ostrobothnia	1 187	1 484	23 379	37 700	24 566	39 183
Southern Savonia	604	756	10 319	13 144	10 923	13 899
Häme	1 680	2 100	5 209	7 521	6 889	9 621
South Karelia	1 463	1 828	7 111	8 970	8 573	10 798
Kainuu	514	643	3 356	3 518	3 870	4 161
Central Finland	1 191	1 489	3 369	3 959	4 561	5 448
Lapland	2 596	3 244	3 033	3 147	5 628	6 392
Pirkanmaa	2 684	3 356	2 852	5 052	5 536	8 407
Ostrobothnia	838	1 047	11 606	26 956	12 444	28 003
North Karelia	533	666	12 142	15 187	12 674	15 853
Nothern Ostrobothnia	1 990	2 488	6 362	9 724	8 352	12 212
Northern Savonia	2 017	2 522	3 135	3 879	5 152	6 401
Satakunta	1 956	2 444	2 352	5 934	4 308	8 379
Uusimaa	5 404	6 756	1 113	1 827	6 518	8 582
Finland Proper	2 432	3 040	4 715	13 542	7 147	16 582
TOTAL	28 302	35 377	105 011	165 179	133 313	200 556

10.2. Scenario 1

The Uusimaa county with highest sludge amount is a assumed to have sludge incineration plant and the only ASH DEC plant next to it. In addition the counties of Tavastia proper, Kymenlaakso, Päijänne Tavastia, were assumed to be locations for sludge incineration because the counties are close to Uusimaa. Together these 5 counties produce 32 % of the amount of sludge in Finland. In addition the mass densities of sludge ($t/a/km^2$) in these counties are higher than in other counties, which mean shorter distances for sludge transport.

The incinerated amounts of sludge, the resulting amount of ash and the P-rich end product from ASH DEC plant in Uusimaa is presented in Table 12.

Table 12. Used feedstock, resulting amounts of ash and end product in scenario 1.

County	Sludge	Thermal drying Dried sludge		Incineration Ash[1]		ASH DEC End product[2]	
		Min	Max	Min	Max	Min	Max
	t/a	t/a	t/a	t/a	t/a	t/a	t/a
Tavastia proper	18 777	5 100	4 295	653	816		
Kymenlaakso	30 086	7 145	6 017	915	1 143		
Päijänne Tavastia	24 200	6 715	5 655	860	1 074		
Uusimaa	117 000	38 000	32 000	4 864	6 080	10 533	13 166
Finland Proper	68 400	17 100	14 400	2 189	2 736		
Total	258 463	74 060	62 367	9 480	11 850	10 533	13 166

[1]Ash P_2O_5 concentration is in Min 36% and in Max 33%, [2]End product P concentration in Min 14% and in Max 13%

The energy production in scenario 1 is presented in table 13. In Uusimaa the electricity consumed by ASH DEC process is reduced from the amounts of heat and electricity produced with CHP. The use of dried sludge in Uusimaa as a fuel in ASH DEC process reduced the amount of fuel going into CHP and therefore the produced heat and electricity. The ASH DEC process requires less fuel to utilize ash from incineration plant in Uusimaa, because it is assumed that the ash is hot when it comes to ASH DEC process. The ashes from other counties require more fuel since they are colder. More detailed information on energy production and consumption can be found from Appendix 4 table 1.

Table 13. Fuel energy to incineration and net energy production in scenario 1.

County	Fuel energy		Heat		Electricity	
	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a
Tavastia proper	16 648	23 314	8 704	7 564	999	3 381
Kymenlaakso	23 325	32 665	11 288	8 070	1 399	4 736
Päijänne Tavastia	21 920	30 697	11 586	10 309	1 315	4 451
Uusimaa	124 043	173 714	67 712	68 294	6 104	23 126
Finland Proper	55 819	78 171	27 878	21 721	3 349	11 335
Total	241 754	338 562	127 167	115 957	13 167	47 029

10.3. Scenario 2

In the scenario 2 the counties of Pirkanmaa, Nothern Ostrobothnia, Satakunta, Uusimaa and Finland Proper were selected because they have the highest sludge amount and also high sewage sludge density (t/a/km^2). The amount of sludge from these counties comprises 49% of the total sludge amount in Finland. These counties were assumed to have both an incineration plant as well as an ASH DEC plant located close to the incineration plant. Therefore the fuel demand of ASH DEC process is lower when the ash comes directly from incineration.

The incinerated amounts of sludge, the resulting amount of ash and the P-rich end product from ASH DEC plant in Uusimaa is presented in Table 14.

Table 14. Used feedstock, resulting amounts of ash and end product in scenario 2.

County	Sludge	Thermal drying Dried sludge		Incineration Ash[1]		ASH DEC End product[2]	
		Min	Max	Min	Max	Min	Max
	t/a	t/a	t/a	t/a	t/a	t/a	t/a
Pirkanmaa	69 200	18 875	15 895	2 416	3 020	2 684	3 356
Nothern Ostrobothnia	72 845	13 994	11 784	1 791	2 239	1 990	2 488
Satakunta	64 000	13 750	11 579	1 760	2 200	1 956	2 444
Uusimaa	117 000	38 000	32 000	4 864	6 080	5 404	6 756
Finland Proper	68 400	17 100	14 400	2 189	2 736	2 432	3 040
Total	391 445	101 719	85 658	13 020	16 275	14 467	18 083

[1]Ash P_2O_5 concentration is in Min 36% and in Max 33%, [2]End product P concentration in Min 14% and in Max 13%

The energy production in scenario 2 is presented in table 15. The electricity consumed by ASH DEC process is reduced from the amounts of heat and electricity produced with CHP. The use of dried sludge as a fuel in ASH DEC process reduced the amount of fuel going into

CHP and therefore the produced heat and electricity. More detailed information on energy production and consumption can be found from Appendix 4 table 2.

Table 15. Fuel energy to incineration and net energy production in scenario 2.

County	Fuel energy		Heat		Electricity	
	Min	Max	Min	Max	Min	Max
	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a
Pirkanmaa	61 613	86 286	31 831	27 609	3 374	12 041
Nothern Ostrobothnia	45 679	63 971	18 430	6 058	2 501	8 927
Satakunta	44 884	62 857	19 927	11 021	2 458	8 772
Uusimaa	124 043	173 714	69 440	70 514	6 793	24 242
Finland Proper	55 819	78 171	27 468	21 194	3 057	10 909
Total	332 038	465 000	167 096	136 397	18 183	64 891

10.4. Scenario 3

The selected counties for the scenario 3 and the results are presented in table 16. The manure amounts coming to incineration was assumed to be 10% of the total potential of manure. The manure is feedstock only in Southern and Northern Ostrobothnia, because in the other counties the manure amounts (10% of total manure potential) were not significant compared to the amounts of sewage sludge.

Table 16. Used feedstock, resulting amounts of ash and end product in scenario 3.

County	Fresh mass		Incineration		ASH DEC	
	Sludge	Manure	Ash		End product	
			Min	Max	Min	Max
	t/a	t/a	t/a	t/a	t/a	t/a
Southern Ostrobothnia	37 101	43 074	3 172	4 728	3 525	5 254
Pirkanmaa	69 200	0	2 416	3 020	2 684	3 356
Nothern Ostrobothnia	72 845	10 901	2 405	3 228	2 672	3 587
Uusimaa	117 000	0	4 864	6 080	5 404	6 756
Finland Proper	68 400	0	2 189	2 736	2 432	3 040
Total	364 546	53 975	15 046	19 792	16 718	21 991

The energy production in scenario 3 is presented in table 17. The electricity consumption of mechanical dewatering of liquid pig manure and heat required by thermal drying of dewatered pig manure as well as sewage sludge has been subtracted from produced energy amounts. More detailed information on energy production and consumption can be found from Appendix 4 table 3.

Table 17. Fuel energy to incineration and net energy production in scenario 3.

County	Fuel energy		Heat		Electricity	
	Min	Max	Min	Max	Min	Max
	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a
Southern Ostrobothnia	44 958	72 672	24 654	30 731	2 194	7 682
Pirkanmaa	61 613	86 286	31 831	27 609	3 374	12 041
Nothern Ostrobothnia	51 043	75 160	22 138	13 690	2 727	9 595
Uusimaa	124 043	173 714	69 440	70 514	6 793	24 242
Finland Proper	55 819	78 171	27 468	21 194	3 057	10 909
Total	337 476	486 003	175 531	163 738	18 145	64 469

10.5. Scenario 4

The amounts of fresh feedstock and resulting end product amounts from utilizing ash in ASH DEC process in Southern Finland and Western Finland are presented in table 18. In the Southern area the incineration and ASH DEC plants are assumed to be located in Uusimaa and in the Western Finland in Southern Ostrobothnia. These are the ELY centre areas with highest amounts of feedstock. The incineration plant in Southern Ostrobothnia has larger amount of feedstock due to large manure amounts from Southern Ostrobothnia and Ostrobothnia.

Table 18. Used feedstock, resulting amounts of ash and end product in scenario 4.

County	Fresh mass		Incineration		ASH DEC	
	Sludge	Manure	Ash		End product	
			Min	Max	Min	Max
	t/a	t/a	t/a	t/a	t/a	t/a
Häme	42 977	28 910				
Southwest Finland	43 298	20 493				
Uusimaa	117 000	8 599	13 964	19 520	15 516	21 689
Finland Proper	68 400	92 765				
Total	271 675	150 768	13 964	19 520	15 516	21 689
Southern Ostrobothnia	37 101	107 686	16 871	26 748	18 746	29 720
Central Finland	33 954	8 483				
Pirkanmaa	69 200	25 254				
Ostrobothnia	32 659	93 562				
Satakunta	64 000	38 037				
Total	236 914	273 022	16 871	26 748	18 746	29 720

The fuel energy of the feedstock and produced heat and electricity amounts in two incineration plants with ASH DEC treatment are presented in Table 19. The liquid pig manure is assumed to be dewatered at the farms. The thermal drying of pig manure and sewage sludge takes place in the vicinity of the incineration. The dried sludge is assumed to be used as fuel for ASH DEC process. More detailed information on energy production and consumption in the two areas can be found from Appendix 4 table 4.

Table 19. Fuel energy to incineration and net energy production in scenario 4.

County	Fuel energy		Heat		Electricity	
	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a
Uusimaa	290 336	448 554	158 552	179 728	15 554	54 445
Southern Ostrobothnia	268 180	477 994	144 680	205 732	13 837	48 499
Total	558 516	926 548	303 231	385 460	29 391	102 944

11. Discussion

To date the usual treatment method for sewage sludge in Finland is composting or anaerobic digestion. Part of the amount of produced sewage sludge (800 kt/a fresh mass and 160 kt/a TS) could also be incinerated and the residual ashes used in ASH DEC process. Also the residue from anaerobic digestion could be used in incineration after mechanical dewatering and thermal drying.

The ash from manure incineration could be used as fertilizer when the ash meets the requirements for heavy metal concentrations. There were not many sources available for manure ash heavy metal contents, but in general they are suitable for fertilizer on arable land or forest. At least one exception is the digested pig manure slurry ash examined by Kuligowski (2010). The cadmium and zinc concentrations of ash both from incineration and gasification from his study are too high compared to maximum allowable concentrations for fertilizer on arable land in Finland.

Incinerating only manure can be economically difficult to manage because the incineration of manure is in Finland considered as waste incineration. Getting a permit for waste incineration is difficult and also small scale waste incineration is too expensive. However, in some countries (for example Sweden and Germany) horse manure incineration is not considered waste incineration. The manure could act as an additional feedstock in counties with high density of animal husbandry where the land area might not be enough for spreading of manure. Now when the manure acts as a supplementary feedstock beside sludge, the ash can’t be used directly as fertilizer. Then it could be used in ASH DEC process. The perquisite is that the manure producers could pay for the incineration, which might prove problematic.

One of the main consumers of energy in the whole drying, incineration and ASH DEC process is the thermal drying of waste when utilizing wet materials. By using efficient heat exchangers the net heat consumption of the thermal drying can be lowered. The fuel consumption of ASH DEC plant itself can be lowered when it is located close to the incineration plant because the hot ash requires less fuel for heating. Location close to incineration plant cuts down other cost as well when the same infrastructure can be used (roads etc.).

In this study three scenarios were formed each of which had five locations for incineration chosen by the objectives of the scenario. In the first scenario the five incineration plants direct their ash to one ASH DEC plant located close to one of the incineration plants. This way the ash amount to ASH DEC plant is larger (one plant 9.5- 11.9 kt/a ash) than in second and third scenario which affects the economy of the plant. However, the ash coming from other plants is cold and more fuel is needed to heat it than for the hot ash coming from the incineration close by.

In the second scenario the five ASH DEC plants (1.8-6.1 kt/a ash each) are located near the five incineration plants. This way the ash from incineration can be hot and 50% less fuel is needed to heat the ash in ASH DEC process. However, the total net energy production (energy for thermal heating subtracted) per TS (MWh/t_{TS}) is higher in scenario 1 which is a result of higher TS content of the masses in scenario 1 compared to scenario 2 (23% in scenario 1 and 21% in scenario 2 and) which leads to higher energy consumption in thermal drying. The difference of 2 percentage units of TS content has more effect on the net energy production results than 50% fuel saving in ASH DEC process. This has to show that the energy demand of ASH DEC process is low compared to energy production from incineration. The heat production efficiency of the incineration + ASH DEC process is therefore also higher in scenario 1 (53% in min and 34% in max) compared to scenario 2 (50% in min and 29%), while the electricity production efficiency is same in both scenarios (5% in min and 14% in max).

In the third scenario, 10% of the manure is considered to be used as supplementary feedstock in sludge incineration in two of the five locations (Southern and Northern Ostrobothnia, areas of high animal husbandry). The five ASH DEC plants process each 2.2-6.1 kt/a ash, which is quite similar to scenario 2. The manure comprises 13% of the total amount of feedstock for drying and incineration to the five plants, 40% of which is liquid pig manure (3.5-8% TS). Liquid manure requires both mechanical and thermal drying. The heat production efficiency of the incineration + ASH DEC process is 52% in min and 34% in max and electricity production efficiencies 5% in min and 13% in max. The difference in electricity production efficiency is a result of mechanical dewatering that takes place only in scenario 3.

In the fourth scenario 25% of the produced manure in the considered Southern and Western Finland area is assumed to be incinerated along with the sewage sludge. The two ASH DEC plants process now the ash amount of 14-27 kt/a, which is higher than the amount in other scenarios. The manure comprises 45% of the feedstock and 56% of this is liquid pig manure. The mechanical dewatering of liquid pig manure is assumed to be done in the farms. The ash amounts produced in this scenario are nearer to the amounts of ash needed for the ASH DEC plant to become economical.

12. Conclusions

Incinerating the sewage sludge produced in five counties (32% of the total amount produced in Finland) close to each other and utilizing ash in ASH DEC in one of the locations would mean that the plant would receive 9.5-12 kt/a ash and produce 11-13 kt/a P-raw product with P content of 13-14%. On the other hand by incinerating sewage sludge in five counties more further from each other but with highest amount of sludge and high sludge density 49% of the sludge produced in Finland could be reached. Then five ASH DEC plants next to the incineration plants would each utilize 1.8-6.1 kt/ash and produce 2.0-6.8 kt/a P-raw product. Using 10% of manure as a supplementary feedstock in two (high density of animal husbandry) of five counties while utilizing 45% of the sludge produced in Finland does not much increase the ash amount treated in five ASH DEC plants (2.2-6.1 kt/ash each). Incinerating sewage sludge and 25% of the manure in two plants located in Southern and Western Finland could produce ash amounts enough to supply two ASH DEC process located close to these incineration plants (14 kt/a -27 kt/a). In general it seems that incinerating only sewage sludge does not produce enough ash to be treated in ASH DEC plant. Also manure is needed and it could be used as supplementary feedstock in areas of high animal husbandry.

The energy efficiency of the incineration + ASH DEC process is more depended on the TS content and subsequent need for mechanical and or thermal drying than on the energy need of ASH DEC process.

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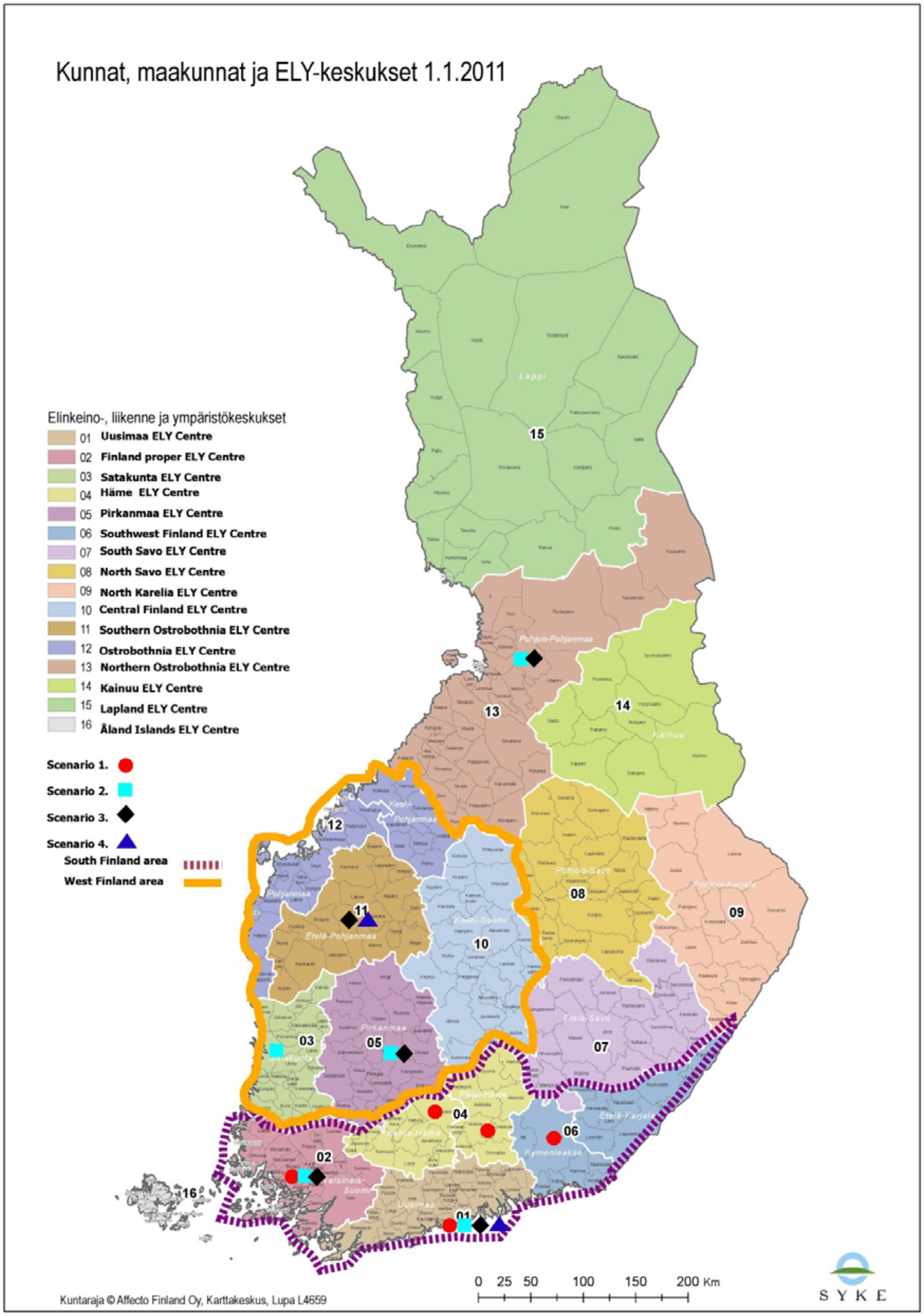
Appendix 1. Map for scenarios (edited from ELY Centre 2011)



Appendix 2. Energy production and consumption from utilizing total potential of sewage sludge in Finland

SLUDGE	Thermal drying		Incineration CHP						ASH DEC			
	Heat		Fuel energy		Electricity		Heat		Electricity		Fuel energy	
County	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a
Åland Islands	7 181	20 918	27 816	38 954	1 669	5 648	20 027	28 826	129	161	567	709
South Karelia	2 418	7 071	10 243	14 344	615	2 080	7 375	10 615	47	59	209	261
Southern Ostrobothnia	6 901	20 119	27 240	38 149	1 634	5 532	19 613	28 230	126	158	555	694
Southern Savonia	2 820	8 310	13 873	19 429	832	2 817	9 989	14 377	64	80	283	354
Kainuu	3 640	10 529	11 800	16 526	708	2 396	8 496	12 229	55	68	241	301
Tavastia proper	3 282	9 689	16 648	23 314	999	3 381	11 986	17 253	77	96	339	424
Central Ostrobothnia	1 107	3 182	2 995	4 194	180	608	2 156	3 104	14	17	61	76
Central Finland	6 138	17 996	27 346	38 297	1 641	5 553	19 689	28 340	127	158	558	697
Kymenlaakso	5 506	16 102	23 325	32 665	1 399	4 736	16 794	24 172	108	135	476	594
Lapland	13 140	38 556	59 573	83 429	3 574	12 097	42 893	61 737	276	345	1 215	1 518
Pirkanmaa	12 078	35 661	61 613	86 286	3 697	12 511	44 362	63 851	285	356	1 256	1 570
Ostrobothnia	5 318	15 348	16 236	22 737	974	3 297	11 690	16 825	75	94	331	414
North Karelia	2 697	7 912	12 226	17 121	734	2 483	8 802	12 670	57	71	249	312
Nothern Ostrobothnia	14 124	40 850	45 679	63 971	2 741	9 276	32 889	47 339	211	264	931	1 164
Northern Savonia	10 213	29 967	46 303	64 845	2 778	9 402	33 338	47 985	214	268	944	1 180
Päijänne Tavastia	4 196	12 407	21 920	30 697	1 315	4 451	15 782	22 716	101	127	447	559
Satakunta	12 060	35 070	44 884	62 857	2 693	9 114	32 316	46 514	208	260	915	1 144
Uusimaa	18 960	56 865	124 043	173 714	7 443	25 189	89 311	128 549	574	717	2 529	3 162
Finland Proper	12 312	36 126	55 819	78 171	3 349	11 335	40 190	57 847	258	323	1 138	1 423
TOTAL	144 092	422 676	649 582	909 700	38 975	131 907	467 699	673 178	3 006	3 757	13 245	16 557

Appendix 3. Energy production and consumption from utilizing the total amount of manures selected for the study.

MANURE	Incineration (energy for drying subtracted f)						ASH DEC energy need			
	Fuel energy		Net heat		Net electricity		Electiricy		Fuel energy	
ELY centre area	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a	Min MWh/a	Max MWh/a
Åland Islands	40 863	44 857	29 421	32 306	2 452	2 731	527	544	2 321	2 396
Southern Ostrobothnia	177 176	345 238	125 358	235 297	9 837	28 867	2 483	4 004	10 942	17 644
Southern Savonia	74 476	78 414	53 572	57 257	4 450	9 582	1 096	1 396	4 829	6 151
Häme	43 721	83 704	30 679	54 743	2 336	4 945	553	799	2 438	3 520
South Karelia	54 995	71 089	39 307	49 609	3 196	6 038	755	953	3 328	4 198
Kainuu	27 399	29 947	19 727	21 595	1 644	1 935	356	374	1 570	1 646
Central Finland	26 820	33 095	19 216	23 293	1 575	2 466	358	420	1 577	1 853
Lapland	24 905	27 298	17 931	19 668	1 494	1 697	322	334	1 419	1 473
Pirkanmaa	24 793	64 278	17 026	40 536	1 191	3 546	303	536	1 335	2 364
Ostrobothnia	100 853	372 552	70 522	253 635	5 299	21 470	1 233	2 863	5 432	12 615
North Karelia	88 746	93 611	63 848	68 293	5 307	10 848	1 289	1 613	5 682	7 108
Nothern Ostrobothnia	49 700	93 867	35 393	65 247	2 841	7 140	676	1 033	2 977	4 551
Northern Savonia	26 229	40 160	18 634	27 173	1 484	2 329	333	412	1 467	1 815
Satakunta	21 821	86 733	14 331	52 798	813	4 547	250	630	1 101	2 777
Uusimaa	9 640	22 693	6 670	14 443	481	1 241	118	194	521	855
Finland Proper	45 001	205 104	28 956	123 574	1 462	10 624	501	1 438	2 206	6 338
TOTAL	837 137	1 692 640	590 592	1 139 467	45 864	120 006	11 152	17 542	49 145	77 304

Appendix 4.

Table 1. Energy consumption and production in scenario 1.

County	Thermal drying		Incineration CHP						ASH DEC			
	Heat		Fuel energy		Electricity		Heat		Electricity		Fuel energy	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a
Tavastia proper	3 282	9 689	16 648	23 314	999	3 381	11 986	17 253				
Kymenlaakso	5 506	16 102	23 325	32 665	1 399	4 736	16 794	24 172				
Päijänne Tavastia	4 196	12 407	21 920	30 697	1 315	4 451	15 782	22 716				
Uusimaa	18 960	56 865	124 043	173 714	7 443	25 189	89 311	128 549	1 119	1 398	3 665	4 581
Finland Proper	12 312	36 126	55 819	78 171	3 349	11 335	40 190	57 847				
Total	44 257	131 188	241 754	338 562	14 505	49 091	174 063	250 536	1 119	1 398	3 665	4 581

Table 2. Energy consumption and production in scenario 2.

County	Thermal drying		Incineration CHP						ASH DEC			
	Heat		Fuel energy		Electricity		Heat		Electricity		Fuel energy	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a
Pirkanmaa	12 078	35 661	61 613	86 286	3 697	12 511	44 362	63 851	285	356	628	785
Nothern Ostrobothnia	14 124	40 850	45 679	63 971	2 741	9 276	32 889	47 339	211	264	466	582
Satakunta	12 060	35 070	44 884	62 857	2 693	9 114	32 316	46 514	208	260	458	572
Uusimaa	18 960	56 865	124 043	173 714	7 443	25 189	89 311	128 549	574	717	1 265	1 581
Finland Proper	12 312	36 126	55 819	78 171	3 349	11 335	40 190	57 847	258	323	569	711
Total	69 534	204 572	332 038	465 000	19 922	67 425	239 068	344 100	1 536	1 920	3 385	4 232

Continuing

Appendix 4. Continuing

Table 3. Energy consumption and production in scenario 3.

County	Thermal drying		Incineration CHP (electricity for dewatering subtracted) [1]						ASH DEC			
	Heat		Fuel energy		Electricity		Heat		Electricity		Fuel energy	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a
Southern Ostrobothnia	7 122	21 665	44 958	72 672	2 618	8 418	32 370	53 305	374	558	825	1 229
Pirkanmaa	12 078	35 661	61 613	86 286	3 697	12 511	44 362	63 851	285	356	628	785
Nothern Ostrobothnia	14 163	41 123	51 043	75 160	3 049	10 098	36 751	55 435	284	381	625	839
Uusimaa	18 960	56 865	124 043	173 714	7 443	25 189	89 311	128 549	574	717	1 265	1 581
Finland Proper	12 312	36 126	55 819	78 171	3 349	11 335	40 190	57 847	258	323	569	711
Total	64 636	191 440	337 476	486 003	20 155	67 551	242 983	358 986	1 775	2 335	3 912	5 146

[1] Electricity need for pig liquid manure dewatering in Southern Ostrobothnia 79 MWh/a in min and 110 MWh/a in max and in Northern Ostrobothnia 14 MWh/a in min and 20 MWh/a in max.

Table 4. Energy consumption and production in scenario 4.

County	Thermal drying		Incineration CHP						ASH DEC			
	Heat		Fuel energy		Electricity		Heat		Electricity		Fuel energy	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a	MWh/a
Uusimaa	47 876	146 668	290 336	448 554	17 420	57 484	209 042	330 152	1 648	2 303	3 631	5 075
Southern Ostrobothnia	45 252	138 920	268 180	477 994	16 091	52 664	193 090	349 799	1 991	3 156	4 387	6 955
Total	93 128	285 589	558 516	926 548	33 511	110 148	402 132	679 951	3 639	5 460	8 017	12 030

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