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Electricity from Poultry Manure: A Clean Alternative to Direct Land Application

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Abstract

In the EU direct land spreading of animal manure is restricted to avoid excessive fertilization of agricultural areas with resulting eutrophication problems. The combustion of poultry manure in biomass power plants is an interesting alternative to direct land spreading. In this paper, the environmental impact of combustion and of direct land spreading of poultry manure are compared, considering three aspects of cleaner production: sustainable energy production and GHG emissions, pollution prevention and recycling of materials.

In a life cycle perspective, it is shown that the production of electricity from poultry manure reduces the emissions of GHGs, NH_3, nitrates, SO_2 and NO_x to the environment. The reduction of the emissions and resulting decreased environmental impact is partly due to the diversion of poultry manure from land spreading and partly due to the replacement of electricity production by the combustion of fossil fuels.

The combustion ash is rich in phosphorus and potassium, but low in nitrogen, so that it can be recycled as an inorganic soil conditioner. The ash is dry, odorless, and free of pathogens, which are beneficial properties compared to fresh poultry manure. Moreover, the amount of heavy metals with respect to the macronutrient phosphate, is unchanged compared to the poultry manure as it enters the combustor. Therefore, land application of the poultry manure ash has the same environmental impact as poultry manure spreading. It may be considered a means to balance the needs and use of phosphorus between regions.

Keywords: Poultry manure, land spreading, combustion, environmental impact

1. Introduction

In Europe, intensive livestock breeding and subsequent land application of animal manure led to excessive fertilization of agricultural areas, with environmental problems as a consequence. For this reason, the EU council, parliament and commission implemented regulations and directives, of which the nitrates directive (91/676/EEC) is the most important. In this directive, limits were set for the application rate of livestock manure, expressed as the amount of nitrogen per hectare of land.

The growing concern about environmental consequences of excessive fertilization necessitates alternative treatment options of animal manure, such as biogas production, refeeding to animals, composting or combustion (Edwards and Daniel 1992, Bolan et al. 2010). Full scale poultry manure combustors are operational in e.g. the UK, the USA and the Netherlands. The primary function of the combustors is the production of electricity, the ash is recycled as a soil conditioner. In order to evaluate the environmental impact of the controlled combustion of poultry manure as an alternative to land spreading, the plant of BMC in Moerdijk (NL) will be studied in this paper.

A comparison will be made between direct land spreading and combustion of poultry manure from a sustainability point of view, based on three aspects of cleaner production: the sustainable production and use of energy (section 3), prevention of the formation and emission of pollutants (section 4) and recycling of materials (section 5).

It will be shown that combustion of poultry manure, with subsequent ash recycling, has two major advantages over its land application: (i) the energy content of the biomass is valorized as renewable energy, and (ii) the nitrogen content is mainly transformed into inert N_2, whereas more valuable components, e.g. phosphate and potassium, are retained in the ash, which is dry, odorless and easy to handle.

2. Poultry manure combustion installation

The studied electricity plant consists of a bubbling fluidized bed combustor, followed by an energy recovery section and an intensive flue gas cleaning installation, including an electrostatic precipitator (ESP), a semidry scrubber with baghouse filter (Turbosorp®) and a selective catalytic reductor (SCR) (Figure 1). The bubbling fluidized bed operates at a temperature of 750-765°C. In the post-combustion zone (freeboard), secondary air is injected and the temperature rises to above 900°C. The ESP removes 97% of the dust from the flue gas. In the Turbosorp® reactor, lime ($Ca(OH)_2$) is added to react with the acid gasses (HCl, SO_2) in the flue gas. In the SCR, NO_x is reduced by the reaction with added NH_3 (200 ton annually), enhanced by a catalyst. For the catalytic reduction, reheating of the flue gas is necessary. This is established by combustion of natural gas in a Hot Gas Generator (HGG).

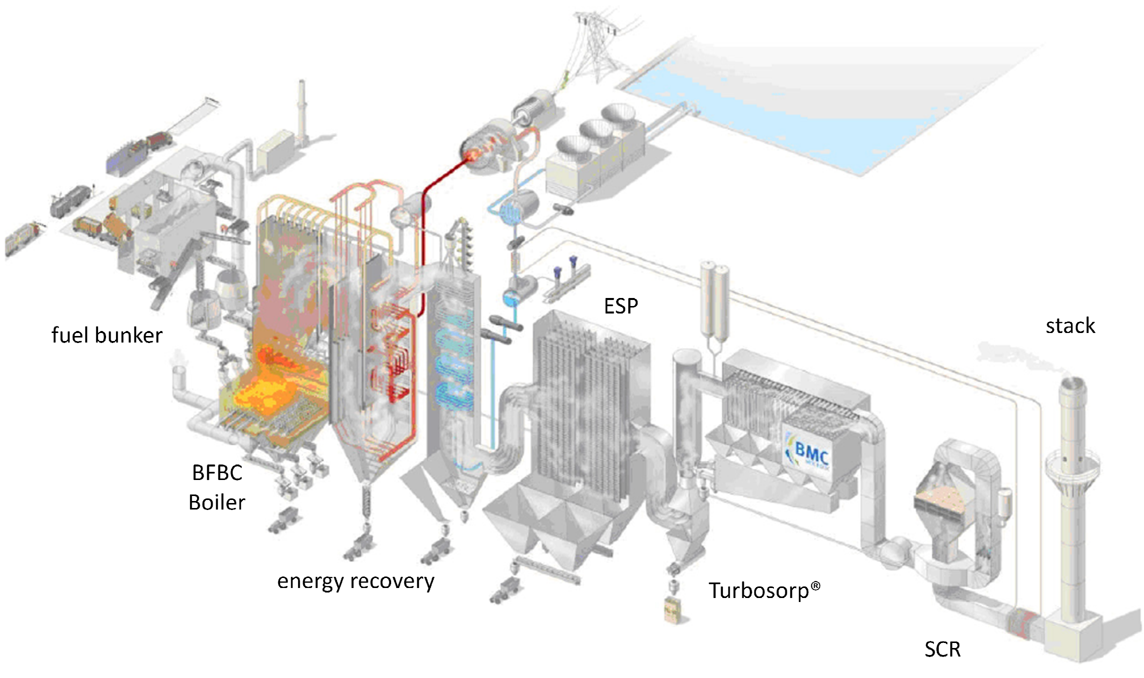

Fig. 1. Process scheme of the studied poultry manure combustion plant

The capacity of the installation is 440 kton of poultry manure per year, originating from more than 600 chicken farms all over the Netherlands. The average composition of the poultry manure is given in Table 1. It was shown in literature that the ammoniacal nitrogen (NH_3-N) can range up to 3 wt% of the wet manure, while only a small fraction (<0.15 wt%) of the wet manure is nitrate (NO_3-N) (Edwards and Daniel 1992).

Tab. 1. Average composition and standard deviation of the poultry manure combusted in the BMC installation. Results from 415 samples evenly distributed in time over a two year period (2010-2011).

		Average	Std. Dev.
Moisture	wt%	44.8	3.0
Ash	wt% DM	21.5	3.1
C	wt% DM	39.1	1.8
H	wt% DM	5.7	1.7
N	wt% DM	4.2	0.7
S	wt% DM	0.7	0.1
Cl	wt% DM	0.5	0.1
Ca	wt% ash	21.0	4.9
Mg	wt% ash	3.7	0.9
K	wt% ash	14.0	3.2
Na	wt% ash	2.2	0.3
P	wt% ash	6.7	1.2

Although the energy production from poultry manure is a proven technology, some challenges remain, related to the nature of the ash. The high phosphorus and potassium concentration in the ash, are responsible for agglomeration in the bed, for the formation of deposits in the freeboard and for fouling of the boiler tubes. These problems can result in unwanted plant shutdowns, with a reduced plant availability as a consequence. Research is currently performed to explain and solve these problems (Billen et al. 2012, Zabetta et al. 2013, Silvennoinen and Hedman 2013).

3. Sustainable energy production and GHG emissions

The combusted poultry manure has a heating value between 6 and 8 MJ/kg. The capacity of the combustion plant is 31 MW_e net, with a net electricity yield of approximately 28%. The efficiency is lower than that of comparable coal plants, because the sticky nature of the ash and corrosiveness of the flue gas limit the steam temperature in the boiler.

Since the emitted CO_2 is biogenic, the direct contribution of the energy production facility to global warming is very limited. Moreover, the green electricity that is delivered to the grid avoids GHG emissions corresponding to 425 kg of CO_2 equivalents per ton of poultry manure[1], by replacing electricity produced from fossil fuels, according to the Dutch energy mix (mainly electricity produced from coal and gas). Other GHG emissions are CO and N_2O. The CO emissions (8.5 mg/Nm³) have a negligible impact on global warming. N_2O on the other hand, is a GHG with a high impact. No N_2O emission data are available for the studied plant, but recent literature shows that for e.g. municipal solid waste incinerators, equipped with an SCR, N_2O emissions are 19-40 mg/Nm³, corresponding to 83-175 g N_2O per ton of fuel (Park et al. 2011). N_2O emissions have a global warming potential (GWP) of 298 kg of CO_2 equivalents per kg (ReCiPe 1.08 Midpoint, Hierarchic perspective). The impact on global warming from N_2O emissions for the studied plant can therefore be estimated at 25-52 kg CO_2 equivalents per ton of poultry manure combusted, corresponding to 3.1-6.6% of the biogenic CO_2 emissions.

The direct GHG emissions from the land application of animal manure mainly consist of biogenic CO_2 and N_2O. For pig manure, N_2O losses range from 0.35% to 2.7% of total nitrogen applied (Prapaspongsa et al. 2010, Meade et al. 2011), but this is strongly dependent on the method of land application (Prapaspongsa et al. 2010). Land application therefore causes an impact on global warming of 40-300 kg of CO_2 equivalents per ton of poultry manure for N_2O emissions alone, assuming that the emissions for poultry and pig manure are comparable. This corresponds to 5-37% of the biogenic CO_2 emissions of the combustion of this poultry manure, which is clearly not negligible, and higher than for the N_2O emissions of poultry manure combustion (3.1-6.6%).

Organic sequestration of carbon is not relevant, as the fertilized land is commonly used for fast

[1] Calculated using GWP 100a (ReCiPe 1.08) impact factor for "electricity, high voltage, at grid NL" (Ecoinvent v2.0)

growing crops, meaning that the carbon will be emitted as CO_2 after a short period of time (months). As land spreading mostly occurs on nearby agricultural land, GHG emissions from transport are considered negligible. A comparison of the impact on global warming from combustion and land spreading of poultry manure is shown in Figure 2.

It should be noted that the impact of combusting poultry manure on global warming is not limited to direct emissions of GHGs. Indirect emissions originate from the production of lime and ammonia, used for flue gas cleaning, start-up fuel, HGG natural gas, transport, and construction of the power plant. The infrastructure if a poultry manure combustion plant is comparable to that of a coal fired power plant. The impact of the construction of the studied poultry manure power plant and the fossil fuel power plants were excluded from this study, as for the electricity production, a facility needs to be constructed in either case. However, this is only an approximation of the real situation.

The low sulfur and chlorine concentration, in combination with the high calcium concentration of the poultry manure ash (binding sulfate and chloride) result in a low lime consumption in the flue gas cleaning installation, approximately 1200 ton per year. The resulting GHG emissions from the production of this lime are 2.1 kg of CO_2 equivalents per ton of poultry manure combusted[2].

Transport of poultry manure to the combustion plant is responsible for 14 kg of CO_2 equivalents emitted per ton, while export of the ash is responsible for another 10 kg of CO_2 equivalents per ton of poultry manure. The natural gas consumption in the HGG corresponds to the emission of 4.5 kg of CO_2 equivalents per ton of poultry manure. Finally, the production of 200 ton of NH_3 to be added to the flue gas in the SCR, is responsible for 0.9 kg of CO_2 equivalents emitted to the atmosphere per ton of poultry manure[3]. The emissions from the SCR process (HGG and NH_3), are low in comparison with other GHG emissions and therefore nearly visible in Figure 2.

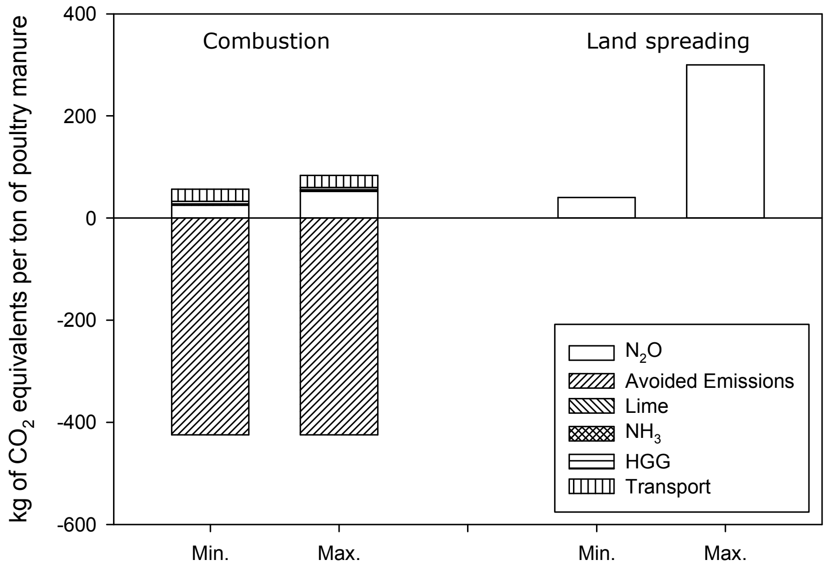

Fig. 2. Impact on global warming of combustion (left) and land spreading (right) of poultry manure. A minimum and maximum value is provided, to cover the ranges of literature data on N_2O emissions.

[2]Calculated using Ecoinvent v2.0, 'lime, hydrated, loose, at plant'
[3]Calculated using Ecoinvent v2.0, 'ammonia, liquid, at regional storehouse'

4. Pollution prevention

The nature of the emissions from a biomass power plant is very different from those due to land spreading of manure. As previously mentioned, N_2O emissions from land application of manure are significant. In addition, ammonia (NH_3) is in most cases emitted to air during the first hours and days after land spreading (Meade et al. 2011). The losses due to NH_3 volatilization range from 2% to 21% of the total N applied on land (Prapaspongsa et al. 2010, Meade et al. 2011). Like most emissions from land spreading, NH_3 volatilization is strongly dependent on factors like climate (e.g. temperature, rainfall intensity), soil type, season, crop type, application method and loading rate (Edwards and Daniel 1992). Since NH_3 has a high impact on terrestrial acidification and a moderate impact on marine eutrophication and particulate matter (PM10) formation, these emissions potentially cause environmental problems. The NH_3 emissions from land spreading of the studied poultry manure range from 1.0 to 10.7 kg NH_3 per ton of poultry manure, while the emissions to air from the combustion plant are approximately 0.017 kg NH_3 per ton. Moreover, the production of electricity to replace electricity from fossil fuels reduces the net increase of NH_3 emissions, as shown in Table 2.

Unlike most solid fuels, where nitrogen is usually organically bound (Vermeulen et al. 2012), a large fraction of the nitrogen in livestock manure is present as NH_3-N (Edwards and Daniel 1992). According to the mechanism described by Vermeulen et al. (2012), this NH_3 reduces the formed NO to N_2 at temperatures of approximately 800°C. This is the main reason for the low NH_3 emissions from the installation. Because of the reactions with the NH_3 present, also the emissions of NO_x are limited. Moreover, a selective catalytic reductor (SCR) before the stack reduces any excess NO_x in the raw flue gas, resulting in average NO_x emissions below 50 mg/Nm³, which corresponds to 0.22 kg NO_x per ton of poultry manure. NO_x has a lower impact on marine eutrophication, particulate matter formation and terrestrial acidification than NH_3, but has also an impact on photochemical oxidant creation and is more toxic than NH_3. However, the NO_x emissions from combusting poultry manure are lower than the NH_3 emissions from land spreading, and lower than the average emission of NO_x from coal and gas power plants in The Netherlands (Table 2), resulting in a net environmental benefit for poultry manure power plants.

Acid gas (HCl, SO_2) emissions from the combustion of poultry manure are limited, due to the low sulfur and chlorine content of the fuel, the presence of a large excess of calcium components in the fluidized bed (Kelleher et al. 2002) and the acid scrubbing in the Turbosorp® reactor by the reaction with lime. The average HCl and SO_2 stack emissions are below 0.1 and 5 mg/Nm³, respectively, corresponding to 0.4 g and 20 g per ton of poultry manure combusted. Although the Turbosorp® system is designed for a recirculation process, the low acid gas concentrations in the flue gas allow the flue gas cleaning residue not to be recirculated. The emissions of SO_2 from poultry manure combustion are much lower than the avoided emissions from fossil fuel combustion (Table 2), resulting in a reduction of the environmental impact when poultry manure is combusted for electricity production.

Tab. 2. Emission data from the combustion of poultry manure and avoided emissions from replacement of electricity from fossil fuels in The Netherlands.

	Direct emissions	**Avoided emissions**[4]
	[in kg per ton of wet poultry manure combusted]	
$CO_{2,\ fossil}$	0	397
CO	0.05	0.09
NO_x	0.22	0.50
NH_3	0.017	0.007
SO_2	0.02	0.24
HCl	0.004	0.003
PCDD/Fs	$< 44 \cdot 10^{-12}$	$22 \cdot 10^{-12}$

The concentration of dioxins and furans (PCDD/Fs) in the flue gas is sufficiently low (<0.01 ng TEQ/Nm³), so that the designed end-of-pipe remediation is not in use. The low PCDD/F formation is

[4] Calculated using Ecoinvent v2.0, 'electricity, high voltage, at grid NL'

probably due to the low chlorine and heavy metal (acting as a catalyst) concentration in the poultry manure. Finally, because of the low heavy metal concentrations in poultry manure, heavy metal emissions to air are far below the regulatory limits.

It is known that poultry manure may cause diseases, due to the presence of pathogens (Edwards and Daniel 1992). The emissions to air and to water of these pathogens are a major disadvantage of land spreading as treatment option for poultry manure. The high turbulence of a fluidized bed combustor promotes efficient heat transfer and uniform mixing, resulting in efficient combustion (Van Caneghem et al. 2012), with destruction of the pathogens from the poultry manure. As the flue gas is subject to temperatures over 850°C, with a residence time of at least 2 seconds, no pathogens are expected to be emitted from the stack.

Whereas the emissions from a poultry manure combustion plant to water are negligible, land spreading of manure to be used as fertilizer causes large emissions to surface and ground water. Among these emissions, the main pollutants are nitrate (NO_3^-), ammonium (NH_4^+), organic N species (e.g. uric acid), organic C. The environmental impact caused by these emissions is mainly in the category eutrophication. Soluble phosphate is also slightly emitted to water, but this is also the case when combustion ash is used as soil conditioner or inorganic fertilizer. As the emissions to water depend to a large extent on several parameters, as described above for emissions to air, no quantitative data are provided.

5. Recycling of materials

In the EU, regulation EC 1774/2002 and directive 91/676/EEC allow the application of livestock manure on agricultural land under certain conditions. The requirements are compliance with maximum allowable N and P application per area of agricultural land and absence of pathogens that constitute a hazard to public health. For manure, no legal restrictions are made concerning the concentration of heavy metals and organic pollutants.

On the other hand, inorganic fertilizers, regulated by EC 2003/2003, are classified as 'EC Fertilizer' or 'Other inorganic fertilizer', according to e.g. the Dutch legislation (Uitvoeringsbesluit Meststoffenwet, Nov. 9th, 2005). For the second category, environmental standards are set for the maximum allowable heavy metal concentrations with respect to the value creating component (e.g. nitrate, phosphate (P_2O_5), potassium oxide, neutralizing capacity, organic content).

To assess of the suitability of the residues from the combustion of poultry manure for use as a fertilizer, attention must be given to: (i) the nutrient value of the inorganic fertilizer and its practical use, and (ii) the environmental impact of ash recycling.

5.1 Nutrient value of poultry manure ash

The bottom ash, the boiler ash and the flue gas cleaning residue from the combustion plant are recycled together as a soil conditioner. The nutrient value of poultry manure ash differs from the initial fuel. The nitrogen content of the poultry manure is volatilized and mainly emitted as N_2 with small amounts of NH_3 and NO_x. The phosphate and potassium content of the fuel are, however, almost entirely retained in the ash. The solubility of the phosphate in water and even in 2% citric acid for manure ash is relatively low (Thygesen and Johnsen 2012). Specifically for the studied poultry manure ash this is on average 0.1% and 5%, respectively, while the total phosphate (P_2O_5) concentration is on average 12%. As the amount of phosphate that is only soluble in mineral acids is too high, the poultry manure ash cannot be classified as an EC Fertilizer (Annex I of EC 2003/2003).

Practically, the poultry manure ash has several advantages over the untreated manure. The fact that (2% citric acid) soluble phosphate and potassium remain in the ash, while nitrogen is removed, makes the poultry manure ash de facto a PK fertilizer. This makes adjustment to the specific fertilization needs more straightforward. Harmful gasous emissions (e.g. NH_3) are avoided due to the absence of nitrogen compounds in the ash. In addition, the ash is odorless, dry and free of pathogens, and thus more suitable for transport and storage than the fresh manure. However, treatment of the ash to reduce the amount of insoluble phosphate would reduce the loss of (globally) scarce phosphate without plant uptake. Research is being performed to increase the plant availability of phosphorus in combustion ash (Thygesen et al. 2011).

As there is an excess of phosphate in agriculture in the Netherlands, the ash of the studied poultry manure combustion plant is currently not applied on Dutch agricultural land. However, the beneficial properties of the ash over the fresh poultry manure, allow export to regions with a phosphate deficit. For the studied combustion plant, the ash is exported to the United Kingdom, Belgium, France and Germany. Combustion of poultry manure may therefore be considered a means to regulate the phosphate balance across regions.

5.2 Environmental impact of ash recycling

Ash from poultry manure combustion can be recycled as a soil conditioner, with phosphate and potassium as macronutrients. National legislation concerning the land application of poultry manure ash differs throughout the EU, and will therefore not be discussed. Mostly, standards are set for the heavy metal concentration of the ash and in some countries the studied ash complies with these standards.

Nevertheless, land application of poultry manure ash does not increase the environmental impact compared to direct poultry manure spreading. The amount of heavy metals in the ash, with respect to the amount of phosphate, is similar to that of fresh poultry manure. The applied fertilization rate is determined based on the phosphorus or nitrogen concentration, so the amount of heavy metals that is spread per hectare of land remains the same.

6. Conclusion

In this paper, it was shown that combustion of poultry manure is a clean alternative for land spreading in for instance The Netherlands. The primary function of the studied poultry manure power plant is the production of electricity. The replacement of electricity from fossil fuels results in a reduction of the emissions of GHGs, NO_x and SO_2. Diverting the poultry manure from direct land spreading results in a reduction of the emissions of NH_3, N_2O, nitrate, organic carbon and pathogens.

Phosphorus and potassium from the poultry manure remain in the ash, in contrast to nitrogen. Furthermore, the ratio of heavy metals to phosphate in the ash equals that of fresh poultry manure. As a consequence, recycling of the ash as a soil amendment does not increase the environmental impact. Moreover, the properties of the ash are beneficial for trading, which allows to improve the regional balance between supply and demand for phosphorus.

In a life cycle perspective, combustion of poultry manure with subsequent ash recycling has thus a lower environmental impact than land spreading, because of the replacement of fossil fuel combustion and the lower emissions of nitrogen compounds (e.g. NH_3 and nitrate).

7. References

Billen, P., Van Caneghem, J., Costa, J., Vandecasteele, C., 2012. Agglomeration and fouling during fluidized bed combustion of waste and biomass described in a common thermodynamic framework. Submitted to Fuel.

Bolan, N.S., Szogi, A.A., Chuasavathi, T., Seshadri, B., Rothrock jr., M.J., Panneerselvam, P., 2010. Uses and management of poultry litter. World’s Poultry Science Journal. 66, 673-698.

Edwards, D.R., Daniel, T.C., 1992. Environmental impacts of on-farm poultry waste disposal – a review. Bioresouce Technology. 41, 9-33.

Kelleher, B.P., Leahy, J.J., Henihan, A.M., O’Dwyer, T.F., Sutton, D., Leahy, M.J., 2002. Advances in poultry litter disposal technology – a review. Bioresource Technology. 83, 27-36.

Meade, G., Pierce, K., O'Doherty, J.V., Mueller, C., Lanigan, G., Mc Cabe, T., 2011. Ammonia and nitrous oxide emissions following land application of high and low nitrogen pig manures to winter wheat at three growth stages. Agriculture, Ecosystems and Environment. 140, 208-217.

Park, S., Choi, J.-H., Park, J., 2011. The estimation of N_2O emissions from municipal solid waste incineration facilities: The Korea case. Waste Management. 31, 1765-1771.

Prapaspongsa, T., Christensen, P., Schmidt, J., Thrane, M., 2010. LCA of comprehensive pig manure management incorporating integrated technology systems. Journal of Cleaner Production. 18, 1413-1422.

Silvennoinen, J., Hedman, M., 2013. Co-firing of agricultural fuels in a full-scale fluidized bed boiler. Fuel Processing Technology. 105, 11-19.

Thygesen, A.M., Wernberg, O., Skou, E., Sommer, S.G., 2011. Effect of incineration temperature on phosphorus availability in bio-ash from manure. Environmental Technology. 32(6), 633-638.

Thygesen, O., Johnsen, T., 2012. Manure-based energy generation and fertilizer production: determination of calorific value and ash characteristics. Biosystems Engineering. 113, 166-172.

Van Caneghem, J., Brems, A., Lievens, P., Block, C., Billen, P., Vermeulen, I., Dewil, R., Baeyens, J., Vandecasteele, C., 2012. Fluidized bed waste incinerators: Design, operational and environmental issues. Progress in Energy and Combustion Science. 38, 551-582.

Vermeulen, I., Block, C., Vandecasteele C., 2012. Estimation of fuel-nitrogen oxide emissions from the element composition of the solid or waste fuel. Fuel. 94, 75-80.

Zabetta, E.C., Barisic, V., Peltola, P., Sarkki, J., Jantti, T., 2013. Advanced technology to co-fire large shares of agricultural residues with biomass in utility CFBs. Fuel Processing Technology. 105, 2-10.