Costs of slurry separation technologies and alternative use of the solid fraction for biogas production or burning – a Danish perspective

BRIAN JACOBSEN[1]

ABSTRACT

The purpose of this paper is to analyse different separation concepts in order to evaluate the overall costs based on a systems approach from stable to field. When livestock are produced in livestock intensive areas the distribution of manure without creating a surplus of nutrients is often a problem. Separation of the slurry into a liquid nitrogen rich fraction and a more solid phosphorus rich fraction, which is exported away from the farm, may alleviate this problem. Separation offers an alternative to transporting the slurry further away, renting more land or buying more land. The need for P-balance is stricter in Denmark than before, but developments in feeding, changes in regulation and the reduction of livestock numbers have made separation less favourable. This article compares dominant separation technologies in Denmark, such as decanter and flocculation, as well as source separation, in order to establish the overall costs. Key parameters are livestock density, transport distance, price of additional land and cost of separation. The conclusion is that unless land prices or prices on slurry agreements are very high, traditional handling of animal manure has the lowest costs. Decanter separation can be the cheapest if area is limited and co-operation with neighbours is possible as large volumes reduce separation costs per tonne. Flocculation is the best if much P has to be removed from the farm in the solid fraction. Separation will in the future in many cases be combined with biogas production as the solid fraction gives a much higher gas production per tonne than slurry.

KEYWORDS: Slurry separation; costs; economics; separation technologies; solid fraction; biogas

1. Introduction

In a number of regions in Europe, the amount of animal manure is high compared to the agricultural land where it can be applied, leading to applications of nitrogen and phosphorus which exceed the crops requirements. These regions cover the Western part of Denmark, The Netherlands (especially the Southeast), Belgium, as well as parts of France and Spain (Brower, 1999). In order to comply with the Nitrate directive (Commission, 1991) and the Water Framework directive (Commission, 2000) lower nutrient application is likely. In the reports to the commission several EU countries note that processing or separation of manure is used in livestock intensive areas (Commission, 2010).

The largest part of slurry is water and it is natural to consider separation of slurry into fractions where the water fraction stays on the farm. This separation can potentially reduce the transportation costs and perhaps storage costs (Burton, 1997 and Jacobsen *et al*., 2002b). In case higher overall utilisation of nutrients in the fractions could be achieved, this would lead to lower purchase of mineral fertiliser. Separation will especially help to decrease the phosphorus load if the phosphorus rich fractions are exported away from the livestock intensive farms (Jacobsen *et al*., 2002b). On the other hand, the use of separation techniques might not reduce the smell from pig production or lower the frequency of animal diseases from slurry as the process does not reduce the number of harmful bacteria (pathogens) (Burton, 2007). The solid fraction from the separation is well suited for biogas plants as the methane production increases with the dry matter content (Møller *et al*., 2004; Møller *et al*., 2007). The alternative is to burn the solid fraction. The area used for applying the manure might be reduced when the environmental regulation related to the Water Framework Directive and the Habitat Directive is implemented (Commission, 1992) is applied and separation is in this case a way to maintain the current animal production at the present location with lower environmental impact.

From an economic perspective, any additional cost related to the processing of slurry has to be recovered in one way or another. This can be through lower transportation costs or higher value of the end product. In other words, the total farm sector benefits have to

[1] Institute of Food and Resource Economics, University of Copenhagen, Rolighedsvej 25, 1958 Frederiksberg C, Denmark. brian@foi.dk

exceed the costs of separation for it to be worthwhile. However, the benefit of using new technologies might include a transfer of income from the animal producer to the arable farmer. Danish arable farmers, who are reluctant to receive slurry from neighbouring farms, do so only if most of the transportation and the application costs are paid by the animal farmer. In some very livestock intensive areas, the receiving arable farmer also receives a per hectare payment from the animal farmer.

The purpose of this paper is to analyse different separation concepts in order to evaluate the overall costs based on a systems approach from stable to field. The paper explains how regulatory changes (livestock density and burning) have changed the uptake of separation technologies. The paper then describes how separation might be combined with biogas production. Furthermore, the paper also looks at whether separation techniques can produce fractions which, on their own, can fulfil the nutrient requirements of the crops.

The paper starts with a short description of the development of the use of separation technologies in Denmark, which is one of the countries in Europe with the highest use of separation technologies. It then goes on to look at the rationale for using separation technologies and the legal restrictions. The paper then describes the costs and revenue related to using the three alternative technologies (decanter, flocculation, source separation) from stable to field on a large pig farm producing 18,000 finishing pigs a year. The effects on changes in land price and transport distance of the ranking of alternatives is discussed in the final section. In the appendix (table A1 to A4), the values for the scenarios are described in more detail.

The paper analyses separation techniques including both the environmental and economic dimension, looking at the entire chain from stable to the field, with a focus on nitrogen usages and phosphorus and the alternative use of the solid fraction.

2. Separation techniques and regulation in Denmark

In a Danish context, the separation technologies have been divided into ''high technology separation'' where the outcome is several fractions, of which one is almost pure water, and ''low technology separation'' which produced two fractions. The high technology separation techniques have been in the developing stages for a number of years, but the approach has been too costly and technically not reliable so the companies have closed down (e.g. Funki Manura and Green Farm Energy). This has left the market to simple, but well tested technologies such as the decanter technology (Jacobsen *et al.*, 2002b, Jacobsen and Hjorth-Gregersen, 2003).

In 2007, 944,000 tonnes of slurry was separated on 51 separation units in Denmark (Landscenteret og KU, 2007). This is equivalent to 3% of the total amount of slurry produced nationwide. The yearly production of manure in Denmark in 2007 was 34 million tonnes of which 27 million tonnes was slurry (liquid), 4.2 million tonnes was deep bedding with much straw) (solid), 0.7 million tonnes was urine (liquid) and 0.7 million tonnes was farm yard manure (solid) (Videncenter, 2008). The solid types of manure have a dry matter content of over 20%.

At all separation units, the slurry is divided into a solid fraction and a liquid fraction. Half of the units were based on slurry from pig production, whereas the other half were based on slurry or degassed material from biogas plants where the raw slurry also might come from a pig farm. Often the liquid fraction is distributed on the local farm, whereas 44% of the solid fraction is exported to other farmers and 31% to the biogas plant (Landscenter and KU, 2007). Only 3% of the solid fraction was burned and the rest is unknown. Most separation units were implemented between 2006–2007, partly because of a 40% investment subsidy in that period (Landscenter and KU, 2007). The Danish Farmers Advisory centre (Frandsen, 2010) estimates that of the units working today, 40% are screw press, 40% band filter and most of the rest decanter centrifuge.

This development fits in very well with the conclusion in a previous report from the Institute of Food and Resource Economics, which concluded that the high technologies plants were too expensive (Jacobsen *et al.*, 2002b). The report showed that the handling of fractions requires new application technologies and a focus on reducing the nitrogen loss at storage. Finally, the report points out that the alternative land price and the income from farming has to be large for even the low technology options to be a profitable alternative to longer transport or renting more land. The decanter separation units might in some cases be worthwhile as the total costs were lower than traditional handling, but the report pointed out that the lack of a market for the solid fraction was a major problem.

Since the high fertiliser prices in 2008–2009 have caused more arable farmers to be interested in receiving the solid fraction than before, as is also the case with biogas plants as the alternatives have become more expensive (Jacobsen, 2011b). The change has also lead to exchange of manure agreements over the internet, but alternative use of the solid fraction in gardens etc. is still very limited (Jørgensen and Jensen, 2010). Another key factor in the uptake of separation besides the technology and the economics, is the regulation of livestock farms and the need to transport slurry further away.

Area required for animal farms in Denmark

The Danish legislation allows only a maximum of 1.4 livestock units (pigs) and 1.7 livestock units (dairy) per hectare (standard conditions) (Anonymous, 2011). One livestock unit is 100 kg N measured from storage, which includes N-emissions at the storage, but not during application. One livestock unit was previously equal to one dairy cow, but is today equivalent to 0.75 dairy cows or 36 finishing pigs as the developments in feeding over the years has been taken into account. For dairy cows the nitrogen efficiency measures as the ratio between input and output has increased over time. In the United Kingdom 0.87 dairy cow produces 100 kg N (Defra, 2010).

According to the Danish regulation, the agricultural area needed for distribution of slurry needs to be owned, rented or guaranteed by 5 year slurry contracts. A given percentage of this distribution area has to be owned by

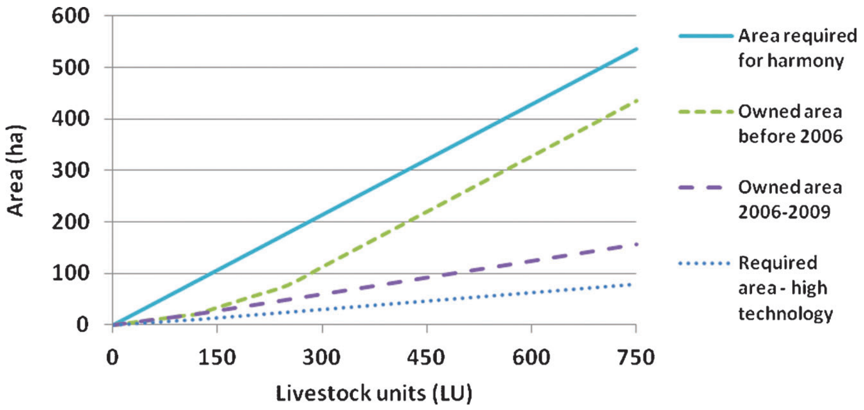

Figure 1: Area required for harmony on a pig farm according to Danish legislation
Source: Own calculations

the farmer, and this percentage increases with farm size. In Figure 1, the top line shows the area required to have harmony between area and livestock production on a pig farm. The top dotted line shows how much of the area required for harmony had to be owned by the farmer before 2006. The area requirement has been relaxed since and was, in April 2010, removed (Anonyms, 2010) so that farmers no longer need to own the area needed for the distribution of their slurry.

The regulation regarding distribution area has helped to avoid a large excess of phosphorus as has been seen in other livestock intensive countries e.g. in the Netherlands where the surplus was 31 kg P per ha in 1998 (Oenema and Berentsen, 2005). As a comparison, the Danish surplus was 11 kg P per ha in 2000 (Jacobsen *et al*., 2004), which is at the same level as the UK, which had a P-surplus of 10 kg P per ha in 2000 (Defra, 2011). In all three countries, the P-surplus in 2010 is lower than it was 10 years ago.

In 2002, an incentive to promote separation was included, as the area requirement was reduced by 25 and 50% for the use of high and low separation technology respectively, but this has later been abolished. The conclusion is that the incentive to support separation in the period 2002–2009 probably did help to increase the number of separation systems implemented as the land prices at the same time were increasing. Furthermore, the relatively low income in pig production in 2008–2010 has also worked against increasing the number of separation units. The total numbers of pigs has decreased by 10% from 14.0 million in the fourth quarter in 2007 to 12.5 million in the third quarter in 2010 (Statistics Denmark, 2010). Also, the total number of livestock in Denmark has decreased by 400,000 livestock units to 2.1 million livestock units in 2009, which is a decrease of 18%. Part of this reduction has happened because of the problems with getting approvals for new animal farms through the new electronic approval system introduced by the Danish Environmental Protection Agency (Husdyrgodkendelse, 2011 and Jacobsen, 2011a).

The lower livestock density has reduced the need for separation technologies as land is easier to come by, which together with the financial crises has reduced land prices. On the other hand, farmers and biogas companies are more willing to buy or receive separation products (solid fraction) than five years ago as they have realized the value of the products in the years with high fertiliser prices. However, the price for the fractions is still low, sometimes zero, even though the nutrient value per tonne is relatively high. This indicates that the barrier for arable farmers to receive slurry is relative high, perhaps based on negative experience and perceptions of the inconveniences.

Burning the solid fraction

An alternative to selling the solid fraction is to burn this fraction, but in 2008 this was only adopted in relation to 1–3 separation plants (Birkmose and Zinck, 2008). A Danish analysis of the costs shows that there can be a little gain from burning the solid fraction if the produced heat can be fully used and the burning facility is a large scale operation (e.g. 62,000 tonne per year) (FVM, 2005; Schou *et al*., 2006; Hjorth-Gregersen and Christensen, 2005). In this case, the heat is sold at €28.8[2] per MWh (or €7.4 per GJ). In the case where the burning is carried out in combination with a biogas plant, it is even more profitable.

The solid fraction can only be burnt in an approved facility. Typically the large burning facilities already fulfil strict rules and have the advantage that they can take large quantities. To allow burning of fractions at the farm separation plants the Danish Environmental Protection Agency would have had to classify the solid fraction as something other than waste (e.g. bio material like straw as advocated by the Farmers' Association (Miljøstyrelsen, 2009c and Birkmose and Zinck, 2008; Hansen *et al*., 2009). The conclusion is that, in a Danish context, the burning of the solid fraction is only possible at centralised plants. Apart from traditional burning, gasification is another option. The difference is that the substance is heated without oxygen and syngas is produced, which is a gas containing CO and hydrogen. Another issue is to what extent the technology used allows for recycling of P. Phosphorus is a limited resource and technologies which result in P-ash which cannot be fully used by plants is less sustainable. Analyses do indicate that the P in ash from burnt solid animal manure can be used by plants, but there are some uncertainty regarding the levels (Petersen and Sørensen, 2008; FVM, 2005).

[2] In mid-October 2011, €1 was approximately equivalent to $1.4 and £0.87

Separation and biogas

Biogas plants today try to use the solid fraction from separation in the production of biogas. Today 6–7% of the slurry is treated in a biogas plant, but the Danish Government intentions are to increase this to 50% based on the Governments Green Growth Plan (Government, 2009). This is part of the strategy to reduce Green House Gas Emissions (Dubgaard *et al*., 2010).

Biogas plants are less profitable than before as plants now have to pay for e.g. fish oil and other gas busting ingredients (see Nielsen *et al*., 2002; Maarbjerg bioenergy, 2005 and Morsø Bioenergy, 2009). The previous guaranteed price in the 2003 agreement was €0.08 per kWh for 10 years and then €0.05 per kWh for 10 years.

The price of €0.10 per kWh in 2010 includes a subsidy of €0.06 per kWh, which is paid by all Danish users of electricity. This higher price of €0.10 per kWh in 2010 for ''green electricity'' has not been able to ensure profitability in new biogas plants although this subsidy in index linked and as such increase over time. The subsidy in Germany is between €0.15 per kWh for large plants (5 MW) and €0.25 per kWh for small plants (150 kW) (Fuchs *et al*., 2011). The smallest biogas plants get the highest subsidy and it is relatively high even though the heat is often not used. It is, therefore, no surprise that the growth in biogas production at the farm size plants is much higher in Germany than in Denmark at the moment (Fuchs *et al*., 2011).

The advantage of using a biogas plant is the more balanced content of N and P and also that the utilisation of N in digested slurry is higher (lower ammonia emissions), it is free from germs and the smell is reduced. For biogas to expand in Denmark, feeding biogas to the current natural gas grid is an important option. The cost of using natural gas is around €0.36 per m3 methane. Production of biogas based on slurry costs is around €0.54 per m3 methane, increasing to €0.67 per m3 methane when it is upgraded to natural gas level (extracting CO2) (Jensen, 2009). In the case where the current subsidy for green electricity and heating is given to green methane production, the costs would come down to €0.36 per m3 methane, which is similar to the natural gas price (Jacobsen *et al*., 2010). With even conditions between biogas for heating locally and delivery to the natural gas grid, biogas companies would be interested in using this option. Today the biogas companies are restricted as they only have one buyer of the gas, namely the local combined heat and electricity plant. It will also allow the produced energy to be used better in the summer, where the need for heating is low. The introduction of technologies which can reduce the costs of upgrading biogas would further promote this change (Hashøj biogas, 2011).

Reducing P-surplus

Reducing phosphorus surplus is another important reason behind the use of separation, as the Danish environmental target in the Aquatic Plan III is to reduce the P-surplus of 30,200 tonne P in 2001/2002 by 50% by 2015. Feeding practices are changing so that an average pig farm with 1.4 LU/ha today applies 25–30 kg P, where the crops require 20–25 kg P per. ha. In 2002, the feeding norms resulted in an application of 37–44 kg P per ha based on 1.4 livestock units per ha and traditional feeding (Miljøstyrelsen, 2009a). The P-surplus in Denmark in 2009 has been estimated to 7–8 kg P per hectare (DJF, 2009). This development has, in other words, reduced the need to use separation as a way to reduce P application at the farm level. However, some farms might be required to reduce application even below the crop requirements as their P-levels in the soils are very high and the risk for P-levels are high indicating a high risk for P-leaching as the soil is saturated (Jensen, 2010).

3. Analysis of costs

For the purpose of this analysis, traditional handling of slurry is compared with separation in the stable, decanter separation and flocculation (se figure 2). With all the separation techniques, the end product is a liquid fraction and a solid fraction. The nutrient content will vary with the technology (see table 1). The separation can be carried out at the farm or at a centralised location (e.g. biogas plant), but in this analysis, it is assumed to be carried out at the farm level either through a fixed or mobile separator. The analysis looks at the entire chain from stable to field and includes the costs for storage, separation, transport and additional purchase of mineral fertiliser to fulfil the nutrient requirement of the crops. Based on the description above, a number of relevant scenarios for the use of separation techniques have been set up. They are (see appendix A for more detail):

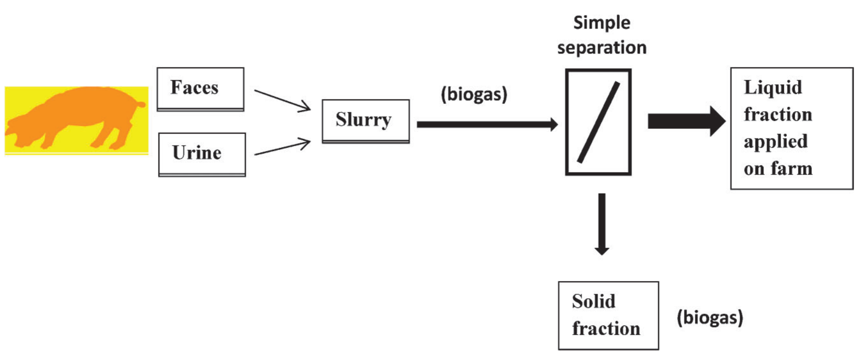

Figure 2: Slurry separation.
Source: after Møller and Sommer, 2002

International Journal of Agricultural Management Jacobsen text to CW 24-10-11.3d 7/12/11 18:14:55
The Charlesworth Group, Wakefield +44(0)1924 369598 - Rev 7.51n/W (Jan 20 2003)

Table 1: Content of the liquid fraction (% of the total content in slurry)

	Decanter (1	Flocculation (2	Source separation and screw press (3
Amount (tonnes)	91	80–90	45
Total N	73	60–70	47
NH4-N	85	85–95	
Total P	(25) 40	1–50	57
Total K	90	80	42
Dry matter	30	8–36	79
Utilisation of N i fraction	85	85	80
Effective N:P index		6–7	

Sources:
1) Landscenteret (2009)
2) Al-2 (2010)
3) Kai, 2010.
Note: Loss of N in the stable is 11% and loss in storage is 2% for slurry and liquid fraction.

Scenario 1: Traditional stable, storage and local distribution of slurry (203 and 357 ha);
Scenario 2: Traditional stable, separation (decanter) (stationary or mobile), farm use liquid fraction, transport and application of solid fraction (30 km), (203 ha);
Scenario 3: Traditional stable, separation (flocculation), farm use liquid fraction and transport and application of solid fraction (30 km), (203 ha);
Scenario 4: Separation in stable and screw press, farm use liquid fraction and transport and application of solid fraction (30 km), (203 ha).

The case farm is a pig farm which would like to expand from 250 LU to 500 LU enabling him to produce 18,000 finishing pigs a year. The crop rotation is barley, oilseed rape, wheat (1 year) and wheat (2 year). The N application follows the Danish N-norms, which is a legal requirement for clay soil (Danish Plante Direktorate, 2009). The average N application is 155 kg N per ha.

Loss of N in the stable is 11% and loss in storage is 2% for slurry and liquid fraction, but 28% for the solid fraction (with cover). (Hansen *et al*, 2008; Miljøstyrelsen, 2009b; Miljøstyrelsen, 2010). The utilisation of N in the field is based on trials (Petersen and Sørensen, P, 2008; Sørensen, 2006 and Birkmose *et al.*, 2003; Jacobsen *et al.*, 2002b). The amount of nitrogen applied on the field is the same for all systems.

The storage cost is an average based on Jacobsen *et al.* (2002a). The storage cost is €2.3 per tonne slurry, whereas the average cost when they are divided into two fractions is €2.5 per tonne (Jacobsen *et al.*, 2002b). A larger slurry storage (3,500 m3) is normally cheaper per tonne (€1.7 per tonne per year) compared with the small storages (1,500 m3), which have an annual cost of €2.4 per tonne (Jacobsen *et al.*, 2002a).

The value of the slurry applied on the field is around €5.1 per tonne based on the content of N, P, and K and a utilisation of N of 75%, of which 65% is the first year effect. In e.g. England the requirements regarding utilisation are lower (Defra, 2011). This is partly because only the first year effect is included. The share of applied total N applied for pig slurry is assumed to be 25–45% when applied in Winter, 55% based on band spreading (using a hose) in Spring and 60% when using injection in Spring. These values show that application in Winter is not to be recommended and that the expected utilisation levels are lower in England than in Denmark. With higher recommended N-applications per ha, this leads to much higher application of slurry per ha in England than in Denmark (Webb *et al.*, 2006).

The question is to what extent the cost of using more advanced technologies are paid by higher efficiency in application. The answer is that the cost of new technology is only partly paid for in terms of higher N-efficiency. Another issue relates to the application distance. The effective value of slurry is €5.1 per tonne or €127.5 per ha when applying 25 tonnes per ha. The transport costs are €4 per tonne when transported a distance of 30 km. On top come application costs which are €1.7 per tonne for slurry or €42.5 per ha, whereas the application costs using mineral fertiliser are only €20 per ha in Denmark. So the organic manure has a relatively large value, but the transport and application costs are often higher.

Injection in winter crops is still a challenge in a Danish context as the incorporation technology used might harm the plants and lower the yield. The use of band spreading has been standard practice for many years, but Injection technologies (little i) are used more and more and will in the years to come be obligatory on Spring crops and grass. Today, Danish farmers are used to having slurry storage of almost 12 months and try to use approaches which try to achieve a very high utilisation of N in slurry. With N-norms for each crop and required utilisation, it is important to reach the expected utilisation as this cannot be compensated for by buying more mineral fertiliser. In recent years, acidification of slurry with Sulphur acid has been promoted to reduce ammonia emission from livestock farms (Infarm, 2011) and increase the N-uptake by the plants.

The application costs are lower for slurry with hose (band spread) than the application of the solid fraction and the liquid fraction when injected into the soil. It is assumed that the spreading of animal manure costs around €1.7 per tonne when using a hose. The prices are based on contractor prices (Jacobsen *et al.*, 2002a). The application costs are higher in the eastern part than

Table 2: Scenario 1a: Baseline – Traditional handling (203 ha, limited P surplus)

	Tonnes	Nitrogen purchase (Kg N)	Costs (€ per tonne)	Total costs (€ per year)
Amount from stable	8,280			
Amount from storage	8,460		2.3	19,304
Application on field	8,460		1.7	15,103
Mineral fertiliser (N)		11,197		7,783
Transport of slurry	3,649		0.1	490
Sold slurry	3,649		5.1	- 18,419
Total costs			**2.8**	**24,262**
Costs per pig produced			**1.3**	

Note: The slurry for the area which exceeds 203 ha (154 ha) is transported 1 km and sold at full value.
Source: Own calculations

in the western part of Denmark as the competition among contractors is higher (Jacobsen *et al.*, 2002a).

The aim is to ensure that there is no P-surplus on the farm. The farm area before the expansion is 203 ha. The minimum area for harmony is 357 ha, but in that case there will be a little P-surplus. With 403 ha all the slurry can be applied on the fields without any P-surplus. The question is whether to buy or rent another 200 ha, transport 4.230 tonne of slurry or invest in separation technology and export the solid fraction. The fertiliser purchase is based on the price of N, P and K of 0.67, €1.2 and €0.3 per kg (Videncenteret, 2010). The utilisation of animal manure is described in the appendix A. When the area is larger than 203 ha, it is assumed that this land is rented and the farmer gets full value for the slurry applied to this area, but the costs of mineral fertiliser needed for this area are not included.

When renting land in livestock intensive areas, the price is higher than in areas without livestock as the opportunity to apply slurry has a value. Danish Statistics have estimated that the additional rent paid in livestock intensive areas is €262 per livestock unit over 1.0 (Danish Statistics, 2010b). With a very high livestock intensity of e.g. 1.5 LU per ha, this would result in an additional rent of €131 per hectare per year. For a farm with 200 ha, this additional cost of having a farm in a livestock intensive area would be €26,200 per year or an additional cost of €3.2 per tonne slurry on the case farm.

Decanter option

With respect to decanter centrifuge, the cost per tonne is smaller when large quantities are processed. The findings show that the cost on a farm with 500 LU is €2.1 per tonne for a stationery unit or €18,400 per year (including investment and maintenance). This is lower than the price of €2.6 per tonne found by Møller and Sommer (2000). The mobile unit costs €35,900 per year with a capacity of 50,000 tonnes per year which gives a total cost of €0.7 per tonne. However, such a capacity requires co-operation and that is sometimes difficult to get to work although there are economic incentives. This would require that the separator works 3,000 hours a year or 9 hours a day, which should be possible (see also Sørensen and Møller, 2006).

The cost of application of the solid fraction on a field 30 km away is included (no sales value). If it is only transported to a biogas plant (and not incorporated), the yearly costs would be reduced by €2,400.

Flocculation

The flocculation approach used here is based on addition of polymers to the slurry. This makes the substance coagulate. Flocculation is caused by polyelectrolytes. A polymer is a large molecule composed of repeating structural units. Approximately 0.2–0.3 litre of polymer is added per tonne slurry. The outcome of the flocculation can be varied more than with a decanter and the amount of P in the liquid fraction can be varied from 1 to 50% of total P (Hjorth *et al.*, 2010). With a production of 8,500 tonne per year, the company AL-2 suggest that their model 2.1 (see table 4) will cover the requirements (AL-2, 2010). The machine takes 3 tonnes per hour and has then to run 3,000 hours a year or 8 hours a day. However, most farmers will probably select the larger model called 3.6M as the additional costs are limited (see table 3). When used to full capacity, the 3.6M would have unit costs of only €1.6–€2.4 per tonne depending on whether it is fixed without screw press or it is a mobile unit (see table 3). Again economics of size is important for the costs per tonne which is treated.

The variable costs are polymer, water and electricity (0.7 kWh per tonne) and a service agreement on the equipment. The variable costs are €1.07–€1.34 per tonne. When using more or less polymer, the nutrient content of the end product can be controlled. The largest model can be mobile and this type has sold a lot, but the idea of several farmers sharing has not always worked. In other cases, it has been owned by the biogas company. The company (AL2) has delivered about 30 of this type to farmers in Denmark.

The actual N-utilisation is 85%, but it can be higher. The solid N can be utilised at 45–50%. With respect to P, the flocculation technique can deliver a wider range than the other technologies. For the nutrient balance to be covered 100%, the share between effective N:P has to be around 155 N : 22 P or 7:1. Another index is the separation index which shows how much of the selected nutrient is removed in the solid fraction (Hjorth *et al.*, 2010).

For this case farm, the costs of separation and screw press will be around €3.4 per tonne. Again, splitting the use between two farms and increasing the volume would reduce the costs to €2.4 per tonne, but it is not always possible.

With the mobile solution, the total costs are reduced to €8.06 per tonnes or €3.76 per finishing pig. The analysis indicates that flocculation is the most flexible,

Table 3: Costs related to flocculation of slurry (€)

Model name	Model 2.1	Model 2.1 + press Screw	Model 3.6	Model 3.6 + press Screw	Model 3.6 Mobile
Amount	8,280	8,280	8,280	8,280	8,280
Press screw	No	Yes	No	Yes	Mobile
Investment in base	63,760	63,760	68,460	68,460	
Invest in screw press		30,200		30,200	
Container/ building	16,780	16,780	16,780	16,780	174,500
Total investment	**80,540**	**110,740**	**85,240**	**115,440**	**174,500**
Yearly costs					
Building etc. (10 år, 4%)	9,932	13,691	10,926	14,631	21,516
Variable costs	8,859	8,859	11,141	11,141	11,141
Labour (20.1 €/hrs)	3,624	3,624	1,221	1,221	4,027
Total costs (€/ year)	**22,416**	**26,174**	**23,356**	**26,993**	**36,685**
Costs (€/tons) 8.280 tonnes per year	**2.7**	**3.2**	**2.8**	**3.2**	**4.4**
Costs (€/tons) 15,000 tonnes per year	**-----**	**-----**	**1.6**	**1.7**	**2.4**

Note: In other analyses, the labour requirement is smaller than stated above. This, with other adjustments, reduces the costs for the mobile unit to 26.845 € per year or 3.4 € per tonne in case of 8,280 tonne and model 3.6.
Source: AL-2 (2010) and own calculations.

Table 4: Key parameters and costs of the different technologies

	Scenario 1a	Scenario 1b	Scenario 2b	Scenario 3	Scenario 4
Name	Baseline -full value	Baseline-transport	Mobile-decanter	Flocculation	Source separation
Area (ha)	203	203	203	203	203
Transport distance (km)	1	30	30	30	30
P-surplus (kg P/ha)	3	0	0	0	0
Excess K	No	No	Yes	Yes	No
Eff. N:P in liquid fraction	4,0	4,0	8,4	7,7	5,8
Eff. Kg N/tonne	5.6	5.6	10.5 / 4.8*	14.8 / 4.1*	5.2 / 4.9*
Kg P/tonne	1,1	1,1	6,5 / 0,5*	6,5 / 0,5*	1,7 / 0,7*
Value slurry / solid fraction (€/tonne)	5.1	5.1	12.1	13.8	4.8
Economics (1000 €) :					
Storage costs	19.3	19.3	20.0	20.0	20.0
Separation costs	0	0	16.6	20.0	20.0
Application of slurry / liquid fraction	16.0	15.2	19.1	19.1	13.2
Application of solid fraction	0	0	1.7	1.7	6.7
Transport of solid /slurry	0	17.2	3.4	3.4	12.6
Mineral fertiliser	7.8	10.1	1.9	3.5	7.7
Value of slurry / solid fraction	18.4	0	0	0	0
Total costs	**24.3**	**61.6**	**51.5**	**67.5**	**80.3**
Cost per tonne (€/tonne)	**2.8**	**7.2**	**6.2**	**8.2**	**9.7**
Cost per pig (€ / pig prod.)	**1.3**	**3.5**	**2.8**	**3.8**	**4.4**

Note:
*(solid fraction/liquid fraction)
Source: Own calculations

also in terms of being able to fulfil the nutrient requirement. It is possible to apply the fractions so purchase of mineral fertiliser is not needed. This would reduce the cost further by €2,685 per year.

Source separation in the stable followed by screw press

The idea behind this technology is to carry out the separation in the stable and so the output from the stable is a liquid and a solid fraction. The solid fraction is then channelled through a screw press. The liquid part from this process is joined with the liquid part from the stable so that only two products come out of the process, namely a solid fraction from the screw press and a combined liquid product from the stable and screw press. Compared to the other separation techniques, this technique does not take as much P away in the solid fraction.

A stable with source separation increases the total investment by 11% or €14,500 for a stable which can produce 18,000 finishing pigs a year (Høj, 2009). In relation to the total yearly amount of slurry of 8,280 tonnes from the stable, this increases the costs by 1.74

per tonne slurry which is processed. No additional costs related to energy use in the stable are included. On top of that comes the cost for the press screw, which is €3,650 annually. The total cost, including 2% maintenance, is therefore €19,100 per year. It is assumed that the utilisation of the liquid fraction is a little lower than the others and so it is set at 80%. Together with a higher loss in the stable, this system has the lowest N value on the field (56%) (See appendix Table A2).

4. Results

The analysis shows that separation can be a valuable alternative to transport of slurry if the transport distance is 30 km or more, but the cheapest option is to distribute the slurry near the farm on your own fields. In livestock intensive areas, renting a larger area to spread the slurry might cost up to €200 per ha on top of the crop return and this increases the costs from €2.8. to €7.7 per tonne (see table 4). In this case, separation can be a viable alternative.

The analysis shows that decanter separation is the cheapest option as the separation costs are lower than for the other technologies (flocculation and source separation). In order to achieve this low cost per tonne, a mobile decanter has been chosen. If a stationary decanter is the only option, the costs per tonne will increase the separation costs from €0.7 to €2.0 per tonne, increasing the total costs to €7.5 per tonne. The costs are then similar to the costs of flocculation and increased transport. With the separation technologies, the solid fraction can be transported a long distance without increasing the costs dramatically, as an increase from 30 to 50 km only increases the total costs by €0.13 per tonne. In cases where the receiver pays for the application this would reduce costs by €1.7 per tonne.

Source separation comes out as the most expensive option, not so much because of the separation costs, but mainly because a larger amount is left in the solid fraction and so the transport costs are somewhat higher. The costs here are more sensitive to transport distance. The separation and application costs are similar to the costs when using flocculation (mobile system). The advantage of renting / buying land as opposed to slurry agreements and separation combined with export of the solid fraction, is that you keep the full value of the nutrients in the farm system. In cases where the solid fraction was sold at full value, separation technologies would be more profitable for the husbandry farmer. Although the value of the solid fraction is between €9,400 and €14,765, it assumed that the farmer receiving the solid fraction will not pay anything, based on current practice.

As previously mentioned, burning the solid fraction might be an option if the farmer is located near a large plant which can burn the solid fraction. This would only reduce the application costs and the transport would still have to be paid by the farmer. The fraction would not have any sales value, although it would generate heat. With respect to biogas, the farmer could export the solid fraction to a biogas plant, but it is assumed that the plant, based on the current price structure does not pay for this fraction. New farm separation plants might even have to pay to deliver the solid fraction to the biogas plant even though the delivered product gives above average gas yield. With higher prices on gas / electricity, the biogas plant might be able to pay farmers according to the gas potential they deliver.

At one of the newest biogas plants in Denmark (Morsø Bioenergy, 2009), a combination of farm separation and separation at the biogas plant is used. The biogas production per tonne is 3–4 times higher from the solid fraction than slurry (Møller *et al.*, 2004). The analysis here indicates that using flocculation is the best in terms of providing full nutrient coverage with the liquid fraction.

An increase in prices of mineral fertiliser has already increased the willingness among arable farmers to receive slurry. This again reduces the need for separation and long distance transport as more area is available nearby. Higher prices on mineral fertiliser will also make it possible for animal farms to be paid for the animal manure. With the current set up, there is an income transfer from animal to arable farms as arable farms do not pay for the value of the slurry they receive.

Experiences in Denmark have shown that land prices increased in areas where the average livestock density was around 1.2 LU per hectare based on the agricultural area in the Municipality. The maximum in Denmark is 1.4 LU per hectare for pig farms and 1.7 / 2.3 LU per ha for dairy farms, depending on the share of certain crops in the crop rotation (Anonymous, 2010).

As shown in this analysis, the key parameters are how much you have to pay for additional land (buy, rent or slurry agreements), how far the slurry / solid fraction has to be transported, how much the farmer receiving is willing to pay and the costs of the separation.

The conclusions are in line with the results of the analyses which was conducted by The Danish Advisory Centre (Landscenteret, 2009) using a spread sheet model to advise farmers. When farmers are faced with options of either investing in separation, making a slurry agreement, renting land or buying more land, the conclusion is that renting land is often the cheapest, followed by slurry agreements and separation. Buying land comes out as the most expensive option, but this option will, on the other hand give the farmer more long term certainty on the land available (Landscenteret, 2009).

5. Conclusion

The conclusion is that it is not profitable to invest in separation technologies unless the farm is situated in a very livestock intensive area where it is difficult to get rid of the slurry. In general, the separation gives an additional cost which is difficult to justify unless the alternative transport distance is high or land prices are high. The analysis show that it is important to look at the entire chain as the separation technologies have a higher loss of N in storage and application costs are higher. The paper shows that regulation, lower livestock numbers and changes in feeding have made separation less favourable over time. The future for separation in Denmark seems to be in relation to biogas plants. Burning of the solid fraction in Denmark has not been as successful as expected, as it is only allowed and economic viable on large heating plants.

The economics are very much dependant on the neighbouring farms' attitude to slurry and other fractions. The farm exporting will often lose the value of the slurry / solid fraction, but might also have to apply it on the other farm paying the application costs. This will benefit arable farmers.

The policy implications are that legislation which ensures harmony between animal production and agricultural land reduces the use of separation. However, in a time where energy from slurry is a valuable renewable energy source, separation of slurry on the farm or at the biogas plant is an option. For this to happen the value of the biogas has to be such that it can pay for the cost of separation. The high values of fertiliser experienced in 2008 made many farmers realise that animal manure has a value. In the livestock intensive areas in the world (e.g. The Netherlands) separation can provide an opportunity to distribute manure better, but findings from Denmark indicate that it might be difficult to sell the solid fraction. When farm separation is combined with biogas production, only the solid fraction needs to be transported to the biogas plant, but here the separation cost will be relatively high.

About the author

Brian Jacobsen is a graduate from the Royal Veterinary and Agricultural University (RVAU) which is now part of University of Copenhagen. He has a M.Sc. from Reading University and a Ph.D. from RVAU. Current research deals with environmental economics and the costs of reducing N- and P-losses, ammonia emission and emission of green house gases from agriculture. He is also involved in the economics related to the biogas production and the implementation of the Water Framework Directive in Denmark.

Acknowledgements

I am thankful for the research money from the Ministry of Food, Agriculture and Fisheries provided given to the GYLLESEP project. I am grateful to Shirley Jacobsen for proof reading and to two anonymous reviewers who provided very detail comments on earlier drafts of the paper.

REFERENCES

AL-2 (2010). Information sheet about separation. http://uk.al-2teknik.dana9.dk/ Accessed on the 3th November 2011

Anonymous (2010). *Bekendtgørelse om husdyrhold og arealkrav mv. Nr. 947 fra 2006 and Bekendtgørelse af lov om landbrugsejendomme from 2010* [Legal requirements regarding livestock and area requirement]. https://www.retsinformation.dk/Forms/R0710.aspx?id=8750 Accessed on 3th November 2011.

Anonymous (2011). *Bekendtgørelse af lov om jordbrugets anvendelse af gødning og om plantedække. LBK nr 415 af 03/05/2011* [Note on legal requirement about use of fertilizer and crop cover] https://www.retsinformation.dk/Forms/R0710.aspx?id=137028. Accessed on the 3rd of November 2011.

Birkmose, T. and Zinck, A. M (2008). *Status på afbrænding af husdyrgødning i Danmark.* [Status on the burning of animal manure in Denmark]. Notat fra Landscenteret og Dansk Landbrug. http://www.landbrugsinfo.dk/Planteavl/Filer/lpart119_b1.pdf. Accessed on the 3rd of November 2011.

Birkmose, T.; Sørensen, P. and Rubæk, G. (2003). *Utilization and losses of nitrogen and phosphorus from field applied slurry separation products*. Ramiran præsentation. http://www.ramiran.net/doc06/O-24%20Birkmose.pdf Accessed on the 3rd of November 2011.

Brower, F.; Hellegers,P., Hoogeveen, M. and Luesink, H. (1999). *Managing nitrogen pollution from intensive livestock production in the EU*. Report 2.99.04. LEI, The Hague.

Burton, C.J. (1997) *Manure Management – Treatment Strategies for Sustainable Agriculture*. Silsoe Research Institute, Silsoe, UK.

Burton, C.H. (2007). The potential contribution of separation technologies to the management of livestock manure. *Livestock Science*, 112, 208–216.

The European Commission (1991). *The Nitrate directive*. Council Directive 91/676/EEC. http://ec.europa.eu/environment/water/water-nitrates/directiv.html Accessed on the 3rd of November 2011.

The European Commission (1992). *The Habitat Directive.* Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm. Accessed on the 3rd of November 2011.

The European Commission (2000). *The Water Framework directive,* Council directive 2000/60/EC, http://ec.europa.eu/environment/water/water-framework/index_en.html. Accessed on the 3rd of November 2011.

The European Commission (2010). *The implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2004–2007*. Report from the Commission to the Council and the European Parliament. http://ec.europa.eu/environment/water/water-nitrates/pdf/sec_2011_909.pdf. Accessed on the 3rd of November 2011.

Danish Plant Directorate (2009). *Gødningsnormer 2009–2010*. [Danish Fertiliser norms 2009–2010] Plantedirektoratet.

Defra (2011). *Soil Nutrient Balances England – Provisional estimates for 2010. July 2011.* http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-environ-obs-research-soilnutrientbalance-statsnotice-england-110728.pdf Accessed on the 3rd of November 2011.

Defra (2010). *Fertiliser manual (RB209).* Defra. England http://www.defra.gov.uk/food-farm/land-manage/nutrients/. Accessed on the 3rd of November 2011.

Dubgaard, A.; Nissen, C.J. Jespersen, H.; Gylling, M.; Jacobsen, B.H.; Jensen, J.D.; Hjort-Gregersen, K. Kejser, A.T. og Helt-Hansen, Julie. (2010). *Økonomiske analyser for landbruget af en omkostningseffektiv klimastrategi.* [Economic analyses for Agriculture of a cost efficient strategy to reduce Green House Gas Emissions]. Report no. 205 Ministry of Food, Agriculture and Fisheries, Denmark. http://www.foi.life.ku.dk/Publikationer/FOI_serier/Nummererede_rapporter.aspx#2010. Accessed on the 3rd of November 2011.

Frandsen, T.Q. (2010). *Metanudbytter af fiber fraktion fra gylleseperation.* [Methane yields from the solid fraction from slurry separation]. Note. Knowledge Centre for Agriculture. Århus, Denmark.

Fuchs, C., Bogatov, V and Eimannsberger, J. (2011). Competitiveness and Risk of Crop Production, Milk Production and Biogas Production with Respect to Regional Resources. *18th International Farm Management Congress: Thriving in a Global World - Innovation, Co-operation and Leadership*. March 20–25, Christchurch, New Zealand.

FVM (2005). *Rapport fra arbejdsgruppen om afbrænding af fraktioner af husdyrgødning*. [Report from the working group on the burning of fractions from Animal Manure] Ministry of Food, Agriculture and Fisheries, Denmark

Government of Denmark (2009). *Grøn Vækst.* [Green Growth]. April 2009. Copenhagen. Denmark. http://www.mim.dk/NR/rdonlyres/D5E4FC9A-B3AC-4C9A-B819-C42300F23CCA/

0/GROENVAEKST_2904rapporten.pdf Accessed on the 3rd of November 2011
Hansen, M.N., Sommer, S.G., Hutchings, N.J. and Sørensen, P. (2008). *Emissionfaktorer til beregning af ammoniakfordampning ved lagring og udbringning af husdyrgødning.* [Emission factors used to calculate ammonia emissions from storage and application of animal manure]. DJF Husdyrbrug no. 84. Det Jordbrugsvidenskabelige Fakultet, University of Aarhus. Denmark.
Hansen, M.N., Kristensen, J.K. and Kristensen, E.F. (2009). *Forbrænding af fiberfraktionen fra separeret husdyrgødning.* [The Burning of the fiber fraction from animal manure]. Information note. AgroTech and DJF, University of Aarhus.
Hashøj Biogas (2011). *Omkostningerne ved opgradering af biogas kan halveres.* [The cost of upgrading biogas can be halved]. http://www.biopress.dk/PDF/FiB_37-2011_03.pdf Accessed on the 3rd of November 2011
Hjorth, M.; Christensen, K.V., Christensen, M.L. and Sommer, S.G. (2010). Solid-liquid separation of animal slurry in theory and practice, A review. *Agron. Sustain. Dev*., 30, 153–180.
Hjorth-Gregersen, K. og Christensen, J. (2005). *Afbrænding af fiberfraktion fra separeret gylle – Drifts- og samfundsøkonomiske analyser.* [Burning of Fiber Fractions from separated Slurry]. Note. Institute of Food and Resource Economics. Denmark.
Husdyrgodkendelse (2011). *Ansøgningssystemet for miljøgodkendelse af husdyrbrug. Miljøministeriets Informationscenter* [Application system for environmental approval of animal farms]. www.husdyrgodkendelse.dk Accessed on the 3rd of November 2011
Høj, P. (2009). *Investering i kildesepareringsstald overfor traditionel slagtesvinstald*. [Investment in source separation building for pigs compared with traditional building for pigs for slaughter]. Note from Svend Aage Christiansen A/S. Denmark.
Infarm (2011). *Slurry Acidification.* http://www.infarm.dk/documents/00095.pdf. Accessed on the 3rd of November 2011
Jacobsen, B.H.; Abildtrup, J.; Andersen, M., Christensen, T.; Hasler, B.; Hussain, Z.B.; Huusom, H.; Jensen, J.D.; Schou, J.S. og Ørum, J.E. (2004). *Omkostninger ved reduktion af landbrugets næringsstoftab til vandmiljøet* [Costs of Reducing Nutrient Losses from Agriculture]. Report no. 167. Danish Research Institute of Food Economics (English summary).
Jacobsen, B.H.; Sørensen, C.G. og Hansen, J.F. (2002a). *Håndtering af husdyrgødning – en teknisk og økonomisk systemanalyse.* Report no. 138. Danish Research Institute of Food Economics, Denmark (English summary).
Jacobsen, B.H.; Hjorth-Gregersen; Sørensen, C.G. and Hansen, J.F. (2002b). *Separation af gylle – en teknisk-økonomisk systemanalyse.* Report no. 142. Danish Research Institute of Food Economics. Denmark. (English summary).
Jacobsen, B.H. and Hjorth-Gregersen, K. (2003). An economic and environmental analysis of slurry separation. *14th International Farm Management Congress: Farming at the Edge,* 10th–15th August, Perth, Australia [Accessed 3rd November 2011]
Jacobsen, B.H., Jespersen, H.M. and Dubgaard, A. (2010). *Ligevægtspris for biogas under forskellige forhold og konsekvens af upgradering til naturgas.* [Break even price for biogas under different conditions and the consequence of upgrading biogas for the natural gas grid]. Note for the Ministry of Agriculture.
Jacobsen, B.H. (2011a). Reducing ammonia emission in Europe – Costs, Regulation and targets with focus on Denmark. *18th International Farm Management Congress: Thriving in a Global World - Innovation, Co-operation and Leadership*. March 20–25, Christchurch, New Zealand.
Jacobsen, B.H, (2011b). Danish Biogas Plants for Green Livestock: Bio energy production and Nutrient redistribution. Invited Paper for *Global Green Growth Seminar on Green Korea: Challenges, Strategy and Cooperation,* Seoul, South Korea, 15th September. http://www.greenkorea2011.org/archive/presentation2.asp. Accessed on the 3rd of November 2011
Jensen, P.N. (2010). *Status for miljøeffekten af miljøregulering og anden arealregulering.* [Status for the environmental effect of environmental regulation and other types of regulation of the area] Notat. NERI, Aarhus University.
Jensen, T.K. (2009). *Biogas til nettet.* [Biogas for the Grid]. Projekt report. Dansk Gasteknisk Center.
Jørgensen, K. and Jensen, L. S. (2010). *Fibre fra gylleseperation – hvor stor er forskellen i deres kvalitet og hvordan anvendes de optimalt?* [Fiber from slurry separation – how large is the difference in quality and how can they be used optimally?] Danish Crop Conference 2010, pp. 372–373.
Kai, P. (2010). *Description of fractions from Source Separation*. Note from the GYLLESEP project.
Landscenteret og KU (2007). *Status over anvendelse af gylleseparation i Danmark.* [Status over the use of slurry separation in Denmark]. Note. Knowledgecentre for Agriculture and University of Copenhagen.
Landscenteret (2009). *Program til beregning af harmoni.* [Model for calculation the required area for animal farms]. Spreadsheetprogram.
Maabjerg BioEnergy (2005). *Miljømæssige, energimæssige og økonomiske konsekvenser af Maabjerg Bioenergi.* [Environmental, energy and economic consequences of Maabjerg Bioenergy]. Summary.Report. http://www.maabjerg-bioenergy.dk/. Accessed on the 3rd of November 2011
Miljøstyrelsen [Danish Environmental Agency] (MST) (2009a). *Fodring*. [Feeding] http://www.mst.dk/NR/rdonlyres/091AB3EB-6EB1-4808-AF75-F091721DFD57/0/Udkast_Svin_fodring_fosfor.pdf. Accessed on the 3rd of November 2011
Miljøstyrelsen [Danish Environmental Agency] (MST) (2009b). *Overdækning af fiberfraktionen fra separeret gylle* [Cover of the fiber fraction from slurry]. BAT blad. http://www.mst.dk/NR/rdonlyres/A17F76D8-10E9-4305-A5C1-E961B5E359A9/0/Udkast_overd%C3%A6kningaffiberfraktioner.pdf. Accessed on the 3rd of November 2011
Miljøstyrelsen [Danish Environmental Agency] (MST) (2009c). *Præcisering af lovgrundlaget og afklaring af en række fortolkningsspørgsmål vedr. forbrænding og forarbejdning af husdyrgødning.[Interpretating of the legal requirement and answers to questions regarding the burning and processing of animal manure]* Note.
Miljøstyrelsen [Danish Environmental Agency] (MST) (2010). *Separation af gylle med decanter centrifuge* [Separation of slurry using decanter technology] http://www.mst.dk/NR/rdonlyres/D167C805-F3FD-471F-9FC4-6158653426CE/0/Udkast_gylleseparering_dekantercentrifuge.pdf. Accessed on the 3rd of November 2011
Morsø Bioenergi (2009). Biomasse behandling og energiproduktion [Biomass treatment and energy production] http://www.biogasdk.dk/down/semdec07/Morsoe-Bioenergi.pdf. . Accessed on the 3rd of November 2011
Møller, H.B., Lund, I. and Sommer, S.G. (2000). Solid-liquid separation of livestock slurry: efficiency and cost. *Journal of Bioresource Technology*, 74, (2000), 223–229.
Møller, H.B. and Sommer, S. (2002). *Solid liquid separation of livestock slurry.* Helcom 23/2002 Seminar. http://agrienvarchive.ca/bioenergy/download/S1-Sommer_DK.pdf. Accessed on the 3rd of November 2011
Møller, H.B., Sommer, S.G. and Ahring, B.K. (2004). Methane productivity of manure, straw and solid fractions of manure. *Biomass and Bioenergy*, 26, 485–495.
Moller H.B, Hansen J.D, Sorensen C.A.G (2007) Nutrient recovery by solid-liquid separation and methane productivity of solids. Transactions from ASABE) Amercian Society of Agricultural and Biological Engineemers, 50, 193–200. http://asae.frymulti.com/azdez.asp?JID=3&AID=22400&CID=t2007&v=50&i=1&T=2. Accessed on the 3rd of November 2011
Nielsen, L.H.; Hjort-Gergersen, K.; Thygesen, P. and Christensen, J. (2002). *Samfundsøkonomiske analyser af biogasanlæg [Socioeconomic analyses of biogas plants].*

Report no. 136. Danish Research Institute of Food Economics. (English summary)

Oenema, O. and Berentsen, P.B.M. (2005). *Manure Policy and Minas: Regulating nitrogen and phosphorus surpluses in Agriculture of the Netherlands*. OECD report. (2004),67.

Petersen, J. and Sørensen, P. (2008). Loss of nitrogen and carbon during storage of the fibrous fraction of separated pig slurry and influence on nitrogen availability. *Journal of Agricultural Science*, 146, 430–413.

Petersen, J. and Sørensen, P. (2008). *Fastlæggelse af udnyttelse I husdyrgødningen*, [The uttilisation of animal manure] DJF, Århus Universitet. http://www.dmu.dk/fileadmin/Resources/DMU/Vand/11_goedningsvirkning.pdf. Accessed on the 3rd of November 2011

Schou, J.S.; Gyldenkærne, S., Grant, R., Elmegaard, N., Palmgren, E. and Levin, G. (2006) *Miljøkonsekvenser ved afbrænding af husdyrgødning med sigte på energiudnyttelse - Scenarieanalyse for et udvalgt opland.* [Environmental consequences related to the burning of animal manure with focus on energy utillisation]. Report NERI, no. 575

Statistics Denmark (2010a). *Landbrug 2009* [Agriculture 2009]. Danmarks Statistik.

Statistics Denmark (2010b). *Økonomien i landbrugets produktionsgrene 2009* [Income in Agricultural enterprises in 2009]. Danmarks Statistik.

Sørensen, C.G. and Møller, H.B. (2006). Operational and Economic modelling and optimization of mobile Slurry Separation. *Applied Engineering in Agriculture*, Vol. 22, 2, 185–193.

Sørensen, P. (2006). *The fate of nitrogen from animal manure in soil crop systems: Experiences with pig and cattle slurries*. DJF, University of Århus. http://www.aral.lom.it/public/upload/00000311_Rel_03_Sorensen.pdf. Accessed on the 3rd of November 2011

Videncenteret (2008). *Produktion af husdyrgødning fordelt på kommuner.* [Production of animal manure in different Municipalities]. Videncenteret for Landbrug. http://www.landbrugsinfo.dk/Energi/Biogas/Filer/pl_10_383_b2.pdf. Accessed on the 3rd of November 2011

Videncenteret (2010). *Budgetkalkuler 2008–2010*. [Farm budget estimates 2008–2010]

Vinter, F. P. (2008). *Udvikling i landbrugets fosforoverskud og forbrug af foderfosfat*. [Development in the phosphorus surplus from Agriculture]. Notat til vandmiljøplan III. Faculty of Agricultural Sciences, University of Aarhus.

Webb, J., Ryan, M., Anthony, S.G., Brewer, A., Laws, J., Aller, M.F. and Misselbrook, T. H. (2006). Cost-effective means of reducing ammonia emissions from UK agriculture using the NARSES model. *Atmospheric Environment*, 40, pp. 7222–7233.

Appendix

Table A1: Case farm with 250 LU finishing pigs (18,000) and 8,460 tonnes of slurry

Scenario	1	2	3	4
Stable	Traditional	Traditional	Traditional	Source separation
Separation technique	None	Decanter (mobil)	Flocculation (mobil)	Screw press
Storage	Storage with lit (not solid)	Storage with lit and cover on solid fraction	Storage with lit and cover on solid fraction	Storage with lit and cover on solid fraction
Field	Slurry	Liquid fraction	Liquid fraction	Liquid fraction
Export	—	Solid fraction	Solid fraction	Solid fraction
Area on farm	357 / 203	203	203	203
Transport distance (slurry/ solid fraction) (km)	30	30	30	30

Table A2: N –balance for the four systems (liquid/solid) (8,460 tonne)

	Baseline	Decanter	Flocculation	Source separation
From animal	54.360	54.360	54.360	54.360
Loss in stable	−5.870 (−10,8%)	−5.870 (−10,8%)	−5.870 (−10,8%)	−5.870 (−10,8%)
From stable	48.489	48.489	48.489	48.489
Loss in storage *	−970 (−2%)	−4.121 (−2% / −28%)	−5.382 (−2% / −28%)	−6.895 (−2% / −28%)
From storage	47.520	44.368	43,107	41.594
Loss at application	−11.880 (−25%)	−10.146 (−15/−55%)	−9,339 (−10/−50%)	−11.162 (−15/45%)
Field effect (ab animal left)	**35.640 (66%)**	**34.221 (63%)**	**33,908 (62%)**	**30,432 (56%)**

Source: Hansen et al. (2008); Petersen and Sørensen (2008). The solid fraction is covered when stored. *Jacobsen et al. (2002); a loss of 30% was used. There are some uncertainties regarding the exact emissions. The figures in brackets show loss in liquid fraction / solid fraction.

Table A3: Content of nutrients in slurry from stable and application of mineral fertiliser to reach N-norms on case farms (357 ha, 1,4 LU/ha)

	From stable	From storage	On field	Effective application (per ha)	Crop require-ment	Mineral fertiliser (per ha)
Total amount (tonne)	8,280	8,460	8,460	24		
Total N	54,360	47,520	35,640	100	155	55
Total P	9,000	9,000	9,000	25	22	−3
Total K	23,580	23,580	23,580	66	70	4
Dry mater %	7,8	6,6				

Note: Requirements are based on Danish N-requirements (Plantedirektotatet, 2010).
In case the application is higher (e.g. 30 tonne per ha) the P surplus will increase, but the K requirement will be fulfilled by animal manure on its own.

Table A4: Content in slurry in scenario 1 and solid fraction in scenario 2–4

Scenario	1	2	3	4
Name	Baseline	Decanter	Flocculation	Source separation
Share (%)	100	10	10	38
Total N	100	25	35	47
Total P	100	60	55	59
Total K	100	10	10	40
Dry matter %	6,6	32	30	30
N-loss during storage (%)	2	28	28	28
Storage costs (€ /tonne)	2.3	2.4	2.4	2.4
Utilisation of N in manure (%)	75	45	50	50
Effective value (€/tonnes)	5.1	18.1	13.8	4.8
Application cost (€/tonne)	1.7	2.4	2.4	2.4
Transport cost (€/tonnes)	4.0	4.0	4.0	4.0
Methane (Nm3/tonnes)	10–20	60–70	70–85	45–65

Source: Jacobsen et al. , 2002b and Hansen et al. (2008)
Note: There are some uncertainties regarding the methane production per tonne.

International Journal of Agricultural Management Jacobsen text to CW 24-10-11.3d 7/12/11 18:15:12
The Charlesworth Group, Wakefield +44(0)1924 369598 - Rev 7.51n/W (Jan 20 2003)