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The economics of biogas in Denmark: a farm and socioeconomic perspective

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ABSTRACT

Denmark has been one of the leading European Countries in using Biogas for Combined Heat and Power (CHP), since the 1980s. However, in the last two decades, the increase has been limited. A new energy policy aimed at increasing the profitability of biogas was introduced in the spring of 2012. The analysis here shows that the new agreement will improve the profitability of biogas plants and increase the biogas production although the political ambition of an increase from 4 PJ to 17 PJ by 2020 seems unlikely. The analysis shows that biogas plants can be profitable even if the input is a mix of manure and solid fractions/ farm yard manure given the present level of support. The overall production costs are around €0.63 per m^3 methane produced, but they can vary from 0.47–0.78 per m^4 methane produced[3]. The profit in the CASE 2012 analysis is €420,000 per year or 0.0.8 € per m^3 methane. The analysis shows that the profit from upgrading biogas is only to be preferred if the sales price of heat or the amount sold are relatively low. The socioeconomic analyses show that the costs of biogas as a measure to reduce CO_2 emissions are around €151 per tonne CO_2 (€85–266 per ton) and that using maize is an expensive way to reduce emissions of CO_2. In an analysis comparing the Danish and German support system, it has been found that the German socioeconomic costs seem to be five times higher than the Danish, based on the same calculation method. In order to improve profitability and reduce the cost of reducing CO_2 emissions, the input to the biogas plant has to be based more on farm yard manure and deep bedding, although the cost of using these inputs might be higher than was included in the analysis.

KEYWORDS: Economics; upgrading biogas; cost of CO_2 reduction; mitigation

1. Introduction

The EU targets on renewable energy, to whose realisation biogas production contributes, are established to reduce the EU's dependence on fossil fuels and to mitigate the climate changes. Denmark is obligated, by 2020, to decrease its total GHG emissions by 20% in the non-ETS[3] quota sectors (housing, transport and agriculture), compared to the 2005 emission levels (European Council, 2009b and 2009a). Along with several initiatives, the Danish politicians made a 'Green Growth' agreement in 2009, stating that up to 50% of all Danish manure should be utilized in a biogas plant by the year 2020. The Danish aims are, therefore, greater than the European requirements as the aim for 2020 is to increase the share of renewable energy in the total Danish energy supply system to 30% (European Commission, 2011; KEMIN, 2012). The aim for 2050 is a fossil free energy production.

The European biogas production was 8,346 ktoe in 2009 (toe=tonne oil equivalent=42 GJ) (Eurobserv'er, 2010). Of the total production, 52% came from agricultural biogas, 36% from landfill gas and the rest from sewage gas. Half of all biogas produced in EU is produced in Germany. The UK is the largest producer of landfill gas which is used either to produce electricity or is injected into the gas grid. In Denmark, 74% of the 100 ktoe produced comes from agricultural biogas. Germany produces 50% of the EU-electricity which is based on biogas, but only 18% of the EU-heat produced is based on biogas. In 2009 Denmark produced almost as much heat based on Biogas as Germany, the reason being that the combined heat and energy concept used in Denmark has led to a high heat production, whereas Germany has many plants which produce only electricity. The combined approach can give an energy efficiency of 85%, whereas it is around only 40% when only the electricity is used (Jacobsen, 2012). Germany has by far the highest number of biogas plants (over 7,000 farm biogas plants), with Austria (300), Netherlands (100) and Denmark (60). Denmark has the most centralised biogas plants in the EU (20) (Birkmose *et al.*, 2007).

Currently, 7–8% of the manure produced in Denmark is used for energy purposes, which is relatively high in Europe, but much lower than the Danish aim of 50%. This puts the need for expansion of the Danish biogas production into perspective (Olesen *et al.*, 2012). The majority of the Danish centralized biogas plants were built in the period 1987–1996, and 19 of these plants are

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[4] In mid-March 2014, €1 was approximately equivalent to US$1.39, £0.84, and 7.46 Danish Kroner (DKK).

Table 1: Energy price (old and new agreement)

	Old energy agreement, CHP (€/Nm^3 methane)	New energy agreement CHP (€/Nm^3 methane)	New energy agreement, natural gas grid (€/Nm^3 methane)
Governmental subsidy	0.380	0.497	0.497
Natural gas price	0.312	0.312	0.312
-Upgrading costs	0	0	0.168
(Quota value)	0	0	(0.048)
(Green value)	0	0	(?)
Total	**0.692**	**0.810**	**0.642**

Source: Tafdrup, (2012), KEMIN, (2012)

still operative today. Alongside this development, around 60 smaller farm scale biogas plants were established. These are responsible for the small but constant increase in Danish biogas production from the mid 90's until now. The biogas production based on manure, has doubled from 1.5 PJ/year in the year 2000 to 3.0 PJ/year in 2010. The total Danish biogas production was 4.2 PJ/year in 2010 (Energistyrelsen, 2010).

The new Danish energy agreement was implemented in the Spring, 2012. To promote the utilization of Danish manure to energy purposes, the governmental support for biogas-based energy was increased from €0.380/Nm^3 methane to €0.497/Nm^3 methane[5], under the condition that the biomass input consists of at least 75% manure. Furthermore, it became possible to get a subsidy for the injection of biogas into the natural gas grid. Finally, to kick-start the production, an investment subsidy of 30% was given to 19 biogas plant projects in 2012. The higher governmental support and the high investment subsidy together with the increased production and sales opportunities, have improved the regulatory framework and the potential income in the Danish biogas sector.

The purpose of the paper is to analyse whether the new energy deal makes Danish biogas profitable from a company perspective, based on the analysis of a CASE 2012 plant. What are the changes in profitability due to e.g. choice input, price, subsidy and share of maize? Will the price conditions in the new energy agreement be enough to boost biogas production in Denmark to fulfil the political ambitions? Furthermore, the aim is to look at the production of biogas as a measure to reduce CO_2 emissions. Is biogas a cost-effective option and under what conditions? With the rapid expansion of biogas plants in Germany, it is relevant to compare the support system and the socioeconomic costs of CO_2 emission in Germany with the Danish situation, looking at both the farm- and socio-economic incentives.

2. Danish biogas

The new Danish energy agreement has increased the value of biogas. As Table 1 illustrates, the governmental support for Danish biogas has increased by approximately 30% compared to the old energy agreement. Table 1 also shows the total price of biogas when it has been upgraded including the natural gas price, the extra costs related to upgrading the biogas to natural gas quality, the values of unused quotas, and a possible green value of biogas.

As mentioned, Table 1 also illustrates a quota value in relation to biogas on the natural gas grid. This value is not a reality yet, but a certificate system has been implemented in the Danish natural gas grid, so consumers are able to buy the CO_2-neutral biogas instead of the standard natural gas. This option allows the energy company to save quotas and the value is with an EU quota price of €20 per ton CO_2, equivalent to a price of €0.048/Nm^3 methane. It should be noted that the current EU CO_2 quota price is only €3–5 per ton CO_2. The table finally contains a green value, which is the value companies/consumers are willing to pay for the CO_2-neutral energy in order to improve the companies green image. It should be noted that CO_2 in this article refers to CO_2-eqivalents as it includes the full effects of all Green House Gases (GHG).

The change in the regulatory framework, providing the possibilities for upgrading biogas to natural gas quality and injecting it into the natural gas grid, has a huge effect on the sales possibilities of biogas. Earlier, the biogas producers were forced to sell their biogas to the local CHP (Combined Heat and Power) plant, and with no alternative buyer, a relative low price on biogas was standard. With the new energy agreement, the biogas producers have an alternative buyer, which improves their situation when negotiating energy prices. The change, furthermore, enables a production of biogas in remote areas far from any CHP plants, which is necessary, if the target of degassing 50% of the Danish manure production is to be realized.

With the new energy agreement, an investment subsidy of 30% is available for a biogas plant project, if their application was approved by the end of 2012 and with the building starting in 2013. This has resulted in 42 applications and the approval of support for 19 new biogas projects in Denmark. Due to the long ratification process in the EU, the support based on the agreement from 2012 is ready to be paid out only from the end of 2013. The plant size ranges between a reactor capacity of 50,000 tons per year for farm scale biogas plants, to larger centralized biogas plants with the capacity to process almost 500,000 tons of biomass per year.

Finally, the ability to boost the biogas production with energy crops and still be eligible for the governmental support, has also improved the conditions for the biogas producers. After the approving of the new energy agreement, a debate was initiated concerning whether it was wise to subsidize biogas based on energy crops (maize). The concern was that biogas, based on energy crops, does not reduce GHG emissions as efficiently as manure, and that it would not contribute

[5] A Normal Cubic Meter of a gas (Nm3) is the volume of that gas measured under the standard conditions of 0 degrees Celsius and 1 atmosphere of pressure

to the realization of the target of degassing 50% of the Danish manure production by 2020. On that foundation, it was agreed to reduce the eligible share of energy crops in the biogas input mix, from 25% in 2012, to 10% towards 2020, and maybe even to 0% in the following years.

3. Case 2012 biogas plant

The analysis is carried out for a hypothetical biogas plant called Case 2012. In the analysis assumptions regarding the plant size, the biomass input mix, the biogas production, and the energy output has been made based on the conditions in Denmark in 2012 and data from some of the 19 plants which received an investment subsidy in 2012. It is estimated that the average new centralized biogas plant in Denmark will have a capacity to degas approximately 700 ton biomass per day, which amounts to almost 260,000 ton biomass per year. The size of the engine is around 2–3 MW. The biomass input mix is based statements from new and planned Danish biogas plants. The input mix does not provide the highest possible profit for the biogas producer, but it is the most likely combination as the allowed share of maize-silage will be reduced to 10% over the coming years. Furthermore, 12% of fibre fraction was added to boost gas production. It is assumed that organic industrial waste is no longer available for the biogas producers, as it already is fully utilized by the current Danish biogas production. Table 2 illustrates the capacity of the biogas plant, the shares of different biomasses in the input mix and their dry matter content, along with the total biogas and methane production.

A part of the produced biogas is utilized in the engine in the biogas plant as process energy, which receives a governmental subsidy of €10/GJ. It is estimated that the process energy is equivalent to approximately 2 m^3 methane per ton biomass input. Furthermore, 1% of the biogas is lost through flaring, and 10% of the biogas is lost through lack of demand for biogas-based heat in the summer period. The final amount of biogas available for sale is 6.1 million Nm^3 methane per year. The production in the first year is reduced by 25% as the system is not performing at maximum capacity right from the start.

The dry matter content in the Danish manure is one of the most uncertain parameters when estimating the biogas potential for a given biogas plant. This uncertainty exists because the dry matter content varies drastically with the type of manure. The dry matter content in cattle manure is generally the highest, whereas the manure from pigs, especially sow slurry, is lower. The standard Danish values for the dry matter content for 2012 are 4.5% for sow slurry, 6.1–6.6% for slaughter pig manure, and 9.3% for cattle (Århus Universitet, 2012). However, the actual tests show lower dry matter values due to larger water content. The most up-to-date values on the dry matter content in the Danish manure are lower than the standard values. Birkmose *et al.* (2012) estimate the dry matter content in manure from slaughter pigs to be 5.5%, and 4.0% for sow slurry. The dry matter content in cattle slurry is estimated to be 7.5%.

Looking at separated manure, it requires 11.5 tons of cattle manure, or 10.8 tons of pig manure to produce 1 ton fibre fraction with a dry matter content of 33%. As shown in Table 2, the methane production per ton is five-six times higher than for slurry. Maize increases the gas production even more (100 Nm3/ton biomass), but as the crop competes with other crops like wheat, a payment of €41 per ton has to be made to the farmers (Jacobsen *et al.*, 2013).

Instead of boosting the biogas production with energy crops, the biogas producer could use separated manure to increase the dry matter content in the reactor. The gas potential in separated manure is not as high in relation to its price, compared to that of maize silage, so it depends on the price paid for the solid fraction from separation. Here, it is assumed that the biogas plant will have to pay €12.1 per ton of solid fraction the biogas plant receives.

4. Results

The standard centralized biogas plant of 250,000 tonnes per year is estimated to have a plant-investment cost of €10.7 million, followed by additional investment costs in e.g. trucks, land, and pipeline, which bring the total initial investment costs up to €13.2 n. Besides the initial investments, there will, after 10 years, be a need for reinvestments of approximately €2. The annual maintenance costs are €0.2 m. A total of three people will be employed with a salary of €0.2 m per year.

Finally, there are the transport costs. It is estimated that the new centralized biogas plant will have an average distance to its manure suppliers of 14 km. Few plants have invested in manure pipelines to transport the manure and so the main part of the manure is transported by truck. This is one of the most costly parts of biogas

Table 2: Biomass input and production–2012 case biogas plant

Biomass type	Input amounts (ton/year)	Dry matter content (%)	Methane (1000 Nm3/year)	Biogas (1000 Nm3/year)	Methane (Nm3/ton input)	Biogas (Nm3/ton input)
Cattle manure	86,553	7.5	1,039	1,598	12.0	18.5
Pig manure	112,737	4.9	1,237	1,904	11.0	16.9
Seperated pig manure	17,344	30.0	1,082	1,665	62.4	96.0
Separated cattle manure	13,316	30.0	831	1,278	62.4	96.0
Maize silage	25,550	33.0	2,552	4,641	99.9	181.6
Extra (serie-operation)	-	-	674	1,109	-	-
Total	**255,500**	**11.3**	**7,416**	**12,194**	**29.0**	**47.7**

Source: Jacobsen *et al.*, 2013.

production, especially because the manure consists mainly of water. The annual cost of transporting 200,000 tonne of manure amounts to approximately €0.5 m.

The interest used is 7.5%, as banks do not always use the biogas plant as collateral. Therefore, it requires that the farmers can used their farm as collateral for the investment. This can, together with funding from the special credit cooperation (Kommunekredit), give a low interest. In the case that the farmers have low equity and more external capital is needed, it is likely that the average interest would be around 7–8% as external investors are invited in. They will often demand a return of 15% per year on their investment.

Table 3 presents the costs related to a standard centralized biogas plant with the capacity of 700 ton biomass per day. The biomass, in this example, consists of 78% untreated manure, 12% separated manure, and 10% maize silage. The annual costs over the 20 year plant lifetime, are in this case estimated to close to €3.2 m. The costs per m^3 input and produced gas (not sold) gas production are also shown.

The income from a standard centralized biogas plant depends on who the buyer is. By selling the biogas to a local CHP plant, the biogas producer will not get paid for approximately 10% of his energy production due to the low demand for heat in the summer period. On the other hand, if the biogas producer chooses to upgrade his biogas for injection into the natural gas grid, extra costs for upgrading the biogas to natural gas quality will appear. In the best case scenario, the centralized biogas plant is situated near a very large CHP plant which has the capacity to receive and sell all the biogas which is produced. If the centralized biogas plant is located far from the nearest local CHP plant instead, it might be more profitable to inject the biogas into the natural gas grid, despite the extra upgrading costs.

Table 4 illustrates the income from the sale of the methane produced at the standard centralized biogas plant. Besides the methane sale, degassing the manure increases its fertilizing value from which the biogas producer also gains an income. Finally, the biogas producer has to buy the energy crop and pay for the separation of the manure which is used to boost the energy production.

5. Sensitivity analysis

As the calculations show in Table 4, a centralized biogas plant which sells the biogas to a local CHP plant will gain an annual profit of €1.6 per ton biomass, or €0.4 million per year. The basic assumptions are shown in Table A in appendix 1. If the centralized biogas plant were to upgrade its biogas and inject it into the natural gas grid, the calculations would be rather different. The income from gas sale would increase by 6% as all the gas is sold, but the additional costs due to the upgrading is assumed to be €0.13/Nm^3 methane, equivalent to €4.35 per ton biomass. In total, this would give a deficit of €0.1 million per year. However, in the case of an increase in sales price of €1.3 per m3 methane, the profit would be €0.3 m per year. The higher price could come from the need to use Green energy as discussed earlier. Another aspect is that if the natural gas company were the owner of the biogas plants, they would be able to provide the capital at an interest of 3–4% and not 7.5%, which would lower the financial costs by €0.3 m per year.

As shown in Table B in Appendix 1, the highest production costs are related to a large share of slurry and when the dry matter content is low. Low production costs are found in cases with a larger share of deep bedding and when the energy loss is reduced.

There is a need for approximately 20–30 new biogas plants, besides the existing 20 in order to reach the Danish target of 50% of all the manure produced being used in a biogas plant. This potential substantial increase of new biogas plants would mean that they cannot all be located near a local CHP plant, as the available manure becomes increasingly scarce. Some of the new biogas plants need to be located in lower livestock intensive areas, where there are no local CHP plants. Therefore, upgrading to natural gas quality and injecting the biogas into the natural gas grid, becomes the only option. But here also, the higher the quantity, the cheaper the cost of upgrading per unit of methane. Another option would be for farmers to join their farm biogas plant in a biogas grid and connect to an upgrading plant. It is clear, that reaching the target of 50% calls for a high degree of farm participation in biogas production which can be difficult to achieve. A possible distribution of the plants to reach the 50% target based on the lowest transport distance is shown in Jacobsen *et al.* (2013).

6. Calculating CO_2 mitigation costs

The political target within the EU is to reduce the CO_2 emissions by 20% by 2020 for the non-quota sectors

Table 3: Total annual costs for a biogas production (Case 2012)

Annual costs	1000 € per year	€ per ton input	€ per m^3 biogas	€ per m^3 methane
Electricity	193	0.75	0.02	0.02
Investments	1,292	5.08	0.11	0.17
Reinvestments	62	0.24	0.01	0.01
Maintenance	218	0.85	0.02	0.03
Transport of slurry	662	2.59	0.05	0.08
Transport of energy crops	318	1.25	0.03	0.04
Transport reinvestments	76	0.30	0.01	0.01
Running costs	372	1.46	0.03	0.05
Total	**3,192**	**12.5**	**0.26**	**0.43**

Source: Jacobsen *et al.*, 2013

Table 4: Total income and costs

Income	1000 €/year	€/tons input	€/m^3 biogas	€/m^3 methane
Gas sale	5,122	20.00	0.42	0.69
Increased fertilizer value	207	0.81	0.02	0.03
Purchase of biomass	−1,715	−6.71	−0.14	−0.21
Total costs	3.192	12.5	0.26	0.43
Total profit	422	1.6	0.04	0.08

Source: Jacobsen *et al.*, (2013)

(agriculture, housing and transport). Denmark has recently set a higher target of 40% (The Government, 2013). A key question is whether biogas is a cost effective way to reach the target. This type of analysis can be conducted in different ways, but they all include some key questions, which need to be answered:

1. How to calculate the CO_2 effect of replacing current energy with biogas
2. How to include side effects which have an impact on society and other environmental goals
3. Whether product or consumer prices should be used to perform the cost calculations included in the MAC (Marginal Abatement Cost) curves.

Question 1: calculating CO_2 effect

Calculating the CO_2 reduction from changing the present energy form to biogas is mainly done in two ways. One approach is based on a calculation where the current energy source (e.g. natural gas or coal) is replaced by the different types of biomass. Here, the effect of natural gas substitution as well as e.g. lower methane and carbon storage is then calculated and converted to the CO_2 equivalents (see Dubgaard *et al.*, 2011 and 2013). The alternative approach is based on a Life Cycle Analysis (LCA) where the full CO_2 impacts of e.g. the process of building a traditional energy supply and biogas plant is compared (Scholz *et al.*, 2011 and Meyer-Aurich *et al.*, 2012).

Question 2: Side effects

The social economic advantage of the shift to biogas is related to CO_2 emissions, but other factors also need to be valued. In the Danish context, lower N-leaching and reduced smell can be named as two advantages which could be valued. For side effects, where a political target exists, a shadow value, based on the costs of other measures, are used as the price the society will pay for this improvement. In a Danish context, the shadow price has been set as the marginal costs of measures which have been decided politically to reduce e.g. ammonia emission or N-leaching.

Question 3: Prices used

Where most countries use factor prices, the tradition in Denmark has been to use consumer prices in a socio-economic analysis in order to be able to compare costs and benefits. This is because the benefits used are based on consumer estimates which include VAT etc. In order to convert factor prices to consumer prices, a net levy factor of 35% is used to convert the factor costs to consumer costs (Ministry of Finance, 1999). This is also a requirement by the Ministry of the Environment that this approach should be used. Furthermore, the fact that the funds used for the subsidy is generated through a tax increase, creates a deadweight loss which should also be included in the cost calculations. The dead weight loss used is 20%. In total, this means that the Danish socioeconomic costs will always be higher than similar calculations in most other European countries.

7. Mitigation costs in Denmark

Degassing of manure contributes to the reduction of GHG emissions in the agricultural sector. Table 5 illustrates the GHG emission reductions related to the degassing of different types of manure. The calculations show that the total GHG reductions are 18,500 tons CO_2-equivalent per year for the CASE 2012 described earlier. The GHG reduction when using maize has no reduction in relation nitrous oxide (NO) and methane and so the full effect of maize comes through the high energy substitution.

We will now look at the estimation of the side effects. Degassing manure also has the ability to reduce nitrogen leaching to the surrounding water. The effect of reduced nitrogen leaching to the root zone is estimated to be 0.11 kg N/ton manure. Less nitrogen leakage represents a welfare economic benefit through the reduction of a negative externality. The welfare economic value of reduced nitrogen leakage to the root zone is estimated to be €4.1 per kg N. When degassing the manure from a standard sized centralized biogas plant, a welfare economic gain of €0.4 m is generated from reduced nitrogen leakages.

Another of the side effects from degassing manure is that the foul odour emission from manure is drastically reduced. Therefore, when the farmers are fertilizing the fields with the degassed manure, the inconvenience for the neighbours is reduced, which generates a positive welfare economic value. No precise estimate of the odour emission reduction value exists, but studies show that the odour emissions are reduced by approximately 50% (Jørgensen, 2009). Furthermore, degassing manure will result in decreased ammonia emissions when distributed on the fields. The biogas plant also functions as a storage and distributer of the manure, which is a benefit for farmers with too much manure compared to their land size.

Besides the above mentioned welfare economic benefits, the biogas production also increases NO_x emissions, which cause damages of €0.3 per ton degassed biomass. The total cost of the CO_2 emissions is €151/tonne CO_2 based on the average case (see Table 6 and Table B in appendix 1). This is much higher than the current CO_2 EU-quota price of €5–10 per ton.

Table 5: GHG emission reductions from degassing pig and cattle manure on a centralized biogas plant

	Cattle manure	Pig Manure	Fiber Fractions (pigs)	Maize
	(kg CO_2-eq./tonne).			
Natural gas substitution	19.0	18.7	171.3	184.3
Nitrious oxide	12.8	11.2	35.9	0
Methane reduction	1.9	13.2	96.7	−60.2
Carbon storage in soil	−1.4	−1.4	−12.8	0
Total effect	32.3	41.7	291.1	124

Source: Olesen *et al.* (2012)

However, looking at other measures in the non-EU quota sector, the analysis show that the marginal costs of CO_2 reductions when trying to achieve the reduction target of 40% or 4 GT CO_2, is around €130–135 per ton CO_2 (The Government, 2013). In other words, with the ambitious Danish target, a cost of around €130–135 per ton CO_2 is just above the level of future target price. The sensitivity analysis in Table B in Appendix 1 shows that the lowest socioeconomic costs come with a high share of deep bedding, larger plants and lower energy loss, whereas the use of maize and input based on slurry and grass have socioeconomic costs over €250 per ton CO_2.

8. Mitigation costs of Biogas in Denmark compared to Germany

The German biogas production has increased dramatically in recent years due to high subsidies for biogas, but does that also mean that the socioeconomic costs per CO_2 are high? Today biogas covers around 1% of the total energy consumption in Germany, using 800.000 ha of maize in 2010 as most biogas plants have maize as the main input. This has put pressure on dairy farming in Germany as the land prices have increased and the transport of maize even from Denmark (10,000 ha), more than 100 km away, has been a very lucrative business, due to the high German subsidies. The analysis of the costs of production from SABAP shows that electricity from coal and gas costs around 5.5 cent per kWh as opposed to 19.6 cent per kWh, which is the cost for electricity from biogas (SABAP, 2011).

Calculations done by Scholz *et al.* (2011) show the production costs and the CO_2 mitigation costs for a German biogas plant based on a small 500 kW plant. The energy production per year is 4,100 KWh (el) and the CO_2 emission was calculated to be from 0.11–0.4 kg CO_2/kWh_{el} as opposed to 0.6 CO_2/kWh_{el} in the reference system. The net effect was hence 0.21 to 0.5 kg CO_2/kWh_{el}. The mitigation costs are €459–1,135 per ton CO_2 where the lowest cost is related to scenario II based on slurry and maize, including the use of thermal heat. This cost is higher than SABAP (2011), which states a price of €200–300 per ton CO_2 depending on the reference system. This could indicate that the socioeconomic costs, based on LCA, are higher than when based on the direct calculation of CO_2 reduction. This is based on the assumption that the costs of production, the biogas production and the reference energy technology are the same in the two cases.

It is now possible to compare the Danish social costs of biogas with the German costs. First, it can be noted that the Danish costs without side effects and consumer price conversion and deadweight loss are substantially lower €101 per ton compared to €151 per ton when these effects are included (see table 6). The most cost effective method (deep bedding) now has a cost of €25 per ton as opposed to €56 per ton when all taxes are included.

The calculations show that the socioeconomic costs in the German case with use of heat is five times higher than the Danish 2012 case and ten times higher when the heat is not used (which is often the case) (see Table 6). One of the main explanations is the large share of maize used in the German biogas plants. The Danish results also show that the cost when using maize (23% of all input) has twice the socioeconomic costs of the standard case. When the most cost efficient Danish option was used, (deep bedding) the difference to the German costs are even higher. The effect of German biogas can be increased if the present energy mix used in the calculations is changed to 100% coal instead of an average mix. However, if natural gas is used as the current energy input (as in the Danish case), this would reduce the mitigation potential and further increase the German mitigation costs. Looking at other renewable energy options in Germany, analyses have shown, that solar panels also have a mitigation cost of around €500–600/ton CO_2, whereas wind power has a

Table 6: Socioeconomic results–Danish calculation for a Danish biogas plant–700 ton/day

	1000 €/year	€/m^3 biogas	€/m^3 methane
Total costs	5,302	0.43	0.67
Total income	2,872	0.25	0.39
Total value of dead weight loss	730	0.06	0.09
Total value of side effects	301	0.02	0.04
Total deficit (NPV 20 year)	2,791	0.21	0.32
Total CO_2-eq reductions. (ton)	18,4		
MAC (€/ton CO_2-eq.)	151		

Source: Jacobsen *et al.* (2013)

mitigation cost of €40–50 per ton CO_2. In other words, biogas has the same level of abatement costs as biogas in Germany (Marcantonini and Ellerman, 2013).

The promotion of biogas in Germany is related to the need for replacing electricity production from nuclear plants which are phased out by 2022. However, the policy recommendations from 2007 were to use more slurry in biogas and not use the expansion of biogas as a success per say, but let it depend on the most cost efficient strategies. The reasons were that biogas was too costly per ton CO_2, the technology does not improve over time and it affects agricultural production (higher land prices etc.). The recommendation was to base the biogas plants on more slurry and require a higher use of heat. The Scientific Advisory Board was clear in its recommendations, but they were only partly followed in the 2012 policy on biogas support (SABAP, 2011). The high support for biogas is probably also linked to the high political ambitions in Germany of at least 35% renewable energy by 2020, reducing CO_2 emission by 40% by 2020, compared to 1990.

9. Conclusions

As a results of the new energy agreement from 2012 and a new policy objective of using 50% of livestock manure to produce biogas, Danish politicians have changed both objectives and the framework for future biogas production. Based on 18 planned facilities, the average size is expected to be approximately 700–750 m^3 per day or 250,000 tons annually. The new energy agreement gives a direct subsidy of €15.4 per GJ. However, increases in other taxes reduce the net effect to €13.8 per GJ. The increased grants provide a significant boost in earnings, but the selling price in real terms will decline over time as the grants are phased out over time. The calculations show that larger plants have lower costs per m^3 of methane produced. This is due to lower operating costs. The transport distance from the farms to the biogas plant of 14 km is a key parameter here. The analysis shows that almost 40% of all costs are related to transportation costs. The large plants can expect that transport costs per m^3 of methane produced can be increased slightly due to longer driving distances. The withdrawal of support for the construction investment of 30% cost the biogas plant 2 million DKK per year. Losing this support can complicate financing, but the biogas plant should still make a profit without the investment support, but strict planning of e.g. inputs is required. Analyses show that the cost of upgrading biogas for distribution via the natural gas grid is roughly the same for the analyzed upgrading techniques. The total cost of the upgrade is set to 0.13 per m^3 of methane including pressure equalization. Profits after upgrading will be less than when selling to CHP when an acceptable price on heat is given. The natural gas companies are in a key position as they have the capital, and so a partnership with biogas plants could be profitable to both parties. It is estimated that with the new energy deal biogas production in the coming years will increase by around 20 plants, taking the use of animal manure to 20–25%. However, financing and finding locations for new biogas plants are key challenges which must be resolved. The analyses indicate that achieving the objective of using 50% of livestock manure in biogas production by 2020 will be very difficult to achieve. However, even an increase from 8% to 20–25% of slurry going through a biogas plant is a large share in European terms.

The socio-economic cost, by increasing biogas production, has increased with the latest energy plan and the change in calculation methods adopted. The new calculations show that costs of up to €134 per ton CO_2 could be required to reach the Danish targets of a 40% CO_2 reduction in the non-quota sector by 2020. Danish analyses shows that mitigation costs in the transport sector are typically higher than €134 per ton CO_2 (Government of Denmark, 2013).

A comparison with the socioeconomic costs in Germany shows that the German politicians have accepted a cost which seems to be around five times higher than the Danish costs per ton CO_2. Germany seems to have been very eager to make a change (biogas

Table 7: Comparison of socioeconomic costs of CO_2 mitigation through biogas based on different calculation methods

Biogas plant	Method 1	Method 2	Method 3
Sideeffects included	Yes	Yes	No
Consumer prices and deadweight loss	Yes	No	No
Results	€/ton CO_2		
Case 2010 205 report[5]		−24	108
Case 2012[1]	151	85	101
Case 2012 based on deep bedding[2]	56	20	25
German–type 1: Use of heat[3]			459
German–type II: No use of heat[4]			1135

Note: The German method is based on no sideeffects, no change to consumer prices, no dead weight loss and the LCA method for calculating the CO_2 effect
[1]DK-Scenario 0 - CASE 2012 (2 MW, slurry, solid fraction and maize, heat is used)
[2]DK - Scenario 4b–(2 MW, slurry and deep bedding)
[3]GER- Scenario 2: 500 kW, 4.100 MWh, input slurry and maize, heat is used. LCA for CO2 effect. Biogas is replacing current energy mix
[4]GER - Scenario 6: 500 kW, 4.100 MWh, input maize and heat is not used. LCA for CO2 effect. Biogas is replacing current energy mix
[5]Dubgaard *et al.* (2011) FOI report 205
Sources: Jacobsen *et al.* (2013); Scholz *et al.*, 2011 and Dubgaard *et al.* (2011)

and solar power) with high social costs as the consequence of the political choices made.

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Appendix 1: Table A Key assumptions made for the Case 2012 calculation

	Case 2012
Biomass (ton per day)	700
Investment including pipes to CHP unit (million €)	13
Average distance from farms to biogas (km)	14
Interest (%)	7,5
Natural gas real price increase (%)	3
Slurry share of total input (%)	78
Maize share of total input (%)	10
Fibre share of total input (%)	12
Average methane prod. Per ton input (Nm^3/tons)	29
Average sales price for biogas (€/GJ)	19
Energy lost at CHP unit (%)	10
Investment support (%)	0

Source: Jacobsen *et al.* (2013)

Appendix 1: Table B Break even analysis for the Case 2012 biogas plant

	Break even costs (€/Nm3 produced)	Socioeconomic costs (€/ CO_{2eq})
CASE 2012 (700 ton/day)	0.63	151
Larger plant (1000 ton/day)	0.60	138
22% deep bedding	0,47	84
20% maize	0.67	265
93% slurry and 7% grass	0.78	310
Low dry matter content	0.67	159
Lower interest (4.25%)	0.59	---
No loss of energy at CHP unit	0.55	139
Investment support (30%)	0.59	155
Costs after upgrading biogas to natural gas	0.79	228

Note: Based on a production of biogas produced of 7,416 Nm^3. The amount sold after process heat use etc. is 6.102 Nm^3 (82%)
The socioeconomic interest used in the mitigation calculation is 4.25%
See Table A above for the base values
Source: Jacobsen *et al.* (2013)