SOCIO-ECONOMIC EVALUATION OF SELECTED BIOGAS TECHNOLOGIES

Scientific Report from DCE – Danish Centre for Environment and Energy No. 62 2013

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Flemming Møller
Louise Martinsen

Aarhus University, Department of Environmental Science

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Data sheet

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Authors: Flemming Møller, Louise Martinsen
Institution: Department of Environmental Science

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Abstract: Financial and welfare economic analyses are conducted of 15 different biogas production scenarios that vary in terms of plant size and type of input. All considered scenarios lead to welfare economic losses. Overall welfare economic GHG reduction costs seem to increase with increasing crop/crop material share of input, and although the costs vary significantly across scenarios they are quite high for all scenarios. The financial analyses suggest that biogas production generally will be financially profitable for the agricultural sector and local CHP facilities but unprofitable for the biogas plants and the State. Seen from a policy perspective the results highlights the importance of designing regulatory instruments in a way that create incentives for private actors to engage in welfare economically desirable biogas production activities while discouraging the expansion of welfare economically undesirable activities.

Keywords: Biogas production, welfare economic analyses, financial economic analyses, GHG reduction costs

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Preface

This report documents the basic economic analyses conducted as part of a larger interdisciplinary research project (BIOMAN) focussing on the merits of biogas production as a means to improve the Danish agricultural greenhouse gas (GHG) balance. The economic analyses presented in the present report include financial as well as welfare economic analyses of biogas production based on different types of input, and of biogas production plants with different treatment capacities, respectively. The analyses are based on scenario descriptions defined jointly by the participants in the BIOMAN project.

Sammendrag

Rapporten indeholder velfærds- såvel som budgetøkonomiske analyser af i alt 15 forskellige scenarier for biogas produktion. Der arbejdes med 3 anlægstyper (2 fælles anlæg med en daglig input kapacitet på hhv. 500 og 800 tons, samt et gårdanlæg med en input kapacitet på 50 tons per dag) og 5 forskellige input kombinationer: 1) 100 % svinegylle, 2) 75 % svinegylle og 25 % majs, 3) 100 % kvæggylle, 4) 50 % kvæggylle og 50 % kløvergræs, og 5) 100 % kløvergræs. I de to første tilfælde antages input at komme fra konventionelt landbrug, hvorimod det i de tre sidste antages at komme fra økologisk landbrug, der har været fremhævet som en en væsentlig leverandør af input til biogasanlæg, fordi gødningsværdien af restproduktet er særlig vigtig for disse landbrug, der ikke må anvende handelsgødning.

Ved formuleringen af scenarierne er der ikke gjort forsøg på at optimere biogasproduktionen. Scenarierne repræsenterer alene mulige inputkombinationer, som analyseres for deres hhv. velfærdsøkonomiske og budgetøkonomiske fordelagtighed. Forskellen mellem velfærdsøkonomisk og budgetøkonomisk analyse er udførligt beskrevet i Miljøministeriet (2010).

Analyserne viser at biogas produktion i alle de analyserede tilfælde giver anledning til et betydeligt velfærdsøkonomisk tab. Samtidig viser analyserne dog, at det på grund af forskellige tilskuds- og affgiftsfritagelsesregler fra et budgetøkonomisk synspunkt generelt vil være økonomisk rentabelt for landbruget (som leverandør af input) og lokale kraft-varme anlæg at engagere sig i biogas produktion. I modsætning hertil vil det være en underskudsforretning for selve biogasanlægget samt for staten. Set fra et budgetøkonomisk synspunkt varierer den økonomiske fordelagtighed af biogas produktion således på tværs af aktører. I forhold til fortolkningen af resultaterne er det vigtigt at holde sig for øje at resultaterne i høj grad er resultatet af de bagvedliggende antagelser, og hvis disse ændres vil resultaterne også ændres. Resultaterne af analyserne kan således ikke bruges som udgangspunkt for generelle konklusioner vedrørende den velfærdsøkonomiske værdi af biogas. Set fra et reguleringsmæssigt synspunkt illustrerer resultaterne imidlertid de potentielle inefficiencer, der kan opstå som følge af implementering af generelle afgifter og subsidier til fremme af biogasproduktion. Resultaterne af analyserne viser således hvordan afgiftsfritagelser og subsidier bidrager til at gøre samfundsøkonomisk uhensigtsmæssige produktionstilgange privatøkonomisk attraktive. Set fra dette perspektiv understreger resultaterne vigtigheden af at regulering og økonomiske instrumenter designes og målrettes specifikt mod fremme af samfundsøkonomisk hensigtsmæssige produktionsformer. Alternativt, hvis regulering sker på for overordnet et plan så som biogas generelt, indikerer resultaterne således at der er en væsentlig risiko for at der skabes utilsigtede incitamenter for private aktører til at deltage i samfundsøkonomisk uhensigtsmæssige aktiviteter, hvilket i sidste ende resulterer i velfærdsøkonomiske tab.

Biogas produktion nævnes ofte som et vigtigt instrument i forhold til reduktion af drivhusgas (GHG) udledningen. En væsentlig parameter i forhold til at vurdere både den samfundsmæssige fordelagtighed af biogas produktion, samt den relative fordelagtighed af forskellige biogas scenarier, er derfor omkostningen ved reduktion af drivhusgasemissioner, som scenariet giver anledning til – den såkaldte omkostningseffektivitet. De i analyserne beregnede omkostninger ved reduktion af drivhusgasudledningen varierer fra ca. 500 til knap 3.300 DKK per ton CO_2-ækvivalent hvilket indikerer at der er stor variation i økonomien og GHG-reduktionspotentialet i biogasproduktion alt afhængig af input- og anlægstype. Generelt set synes det således at være tilfældet, at GHG-reduktionsomkostningen er højere i de tilfælde hvor der tilsættes plantemateriale end i de tilfælde hvor der udelukkende anvendes gylle som input. Analyserne indikerer således, at værdien af det øgede gasudbytte ikke er tilstrækkelig stor til at kompensere for øgende anlægsomkostninger, omkostningerne forbundet med produktionen af planteinputtet og lavere reduktion af drivhusgasser. I forhold til anlægsstørrelse, så indikerer analyserne at GHG-reduktionsomkostningerne er lavest for gårdanlæggene, og det endda til trods for at gårdanlægsberegningerne er baseret på en antagelse om kun 30 % varmeudnyttelse.

Resultaternes følsomhed overfor ændringer i de antagelser, der ligger til grund for beregningerne af ændringer i GHG-emissioner undersøges ved at gennemføre beregninger, hvor emissionskoefficienterne for varieres. Resultaterne af disse følsomhedsanalyser viser at særligt ændringer i antagelserne omkring N_2O-emissionskoefficienterne har en betydning for resultaterne, og dette gælder i særdeleshed for de scenarier, hvor plantemateriale anvendes som input. Konsekvenserne af at ændre i emissionskoefficienterne for CH_4 og ændringer i jordens kulstof indhold er, med de anvendte minimum og maksimum værdier, langt mindre.

Der er også gennemført følsomhedsanalyser for de store fællesanlægsscenarier vedrørende de forudsatte transportafstande mellem leverandørerne af organisk materiale og biogasanlægget. Selv med en 50 % reduktion af transportafstandene vil de analyserede biogasteknologier dog fortsat være velfærdsøkonomisk urentable.

Summary

The report contains welfare and financial economic analyses of 15 different scenarios for biogas production. The scenarios are defined with reference to three different plant sizes (two joint biogas plant with a daily input capacity of 500 and 800 tonnes respectively, and one farm biogas plant with a daily input capacity of 50 tonnes) and five different input combinations: 1) 100 % pig slurry, 2) 75 % pig slurry and 25 % maize, 3) 100 % cattle slurry, 4) 50 % cattle slurry and 50 % grass clover, and 5) 100 % grass clover. For input combinations 1 and 2 the biomass is assumed to come from conventional agriculture, while it for input combinations 3, 4 and 5 are assumed to come from organic agriculture.

The results of the welfare economic analyses reveals that biogas production in all the cases considered give rise to welfare economic losses. The financial economic analyses show that while biogas production according to the described scenarios is likely to be economically profitable for the agricultural sector and local CHP plants (Combined Heat and Power Generation Plants) it is likely to result in net- losses for the biogas plant as well as the state. Hence, seen from a financial economic point of view, the economic desirability of biogas production varies significantly across different actors. In relation to the interpretation of the results it is important to emphasise that the results are inextricably linked to the underlying assumptions, and if these are changed the results will also change. Consequently the results cannot be used as the base for drawing more general level conclusions regarding the welfare economic desirability of biogas production. Seen from a policy point of view, however, the results serve to illustrate the potential inefficiencies introduced by implementing general tax and subsidy structures favouring biogas production. Hence, the results of the analyses shows how tax exemptions and subsidies contributes to making welfare economically undesirable production approaches financially attractive for private actors. Seen from this perspective, the analysis highlights the importance of targeting policies and designing regulatory instruments in a way that ensures that private actors are provided with incentives to engage in welfare economically desirable biogas production activities and discouraged from engaging in welfare economically undesirable activities.

Biogas production is often mentioned as an important instrument in relation to GHG emissions reductions. In this context, an important parameter not only in relation to determining the welfare economic desirability of different biogas production scenarios, but also the relative desirability of different biogas production scenarios, is the cost of GHG reductions associated with a given scenario, i.e. the cost-effectiveness. The GHG reduction costs for the scenarios considered in the analyses vary from around 500 to around 3,300 DKK per tonne CO_2 equivalent. This indicates that there is great variability in the profitability and GHG reduction potential of biogas production across different plant types and different input combinations. Generally GHG reduction costs appear to be higher for the scenarios involving plant material as an input than for the scenarios solely based on slurry as an input. Hence, it appears that the value of the increased gas production from plant material compared to slurry is insufficient to compensate for the increased investment costs, the costs associated with producing the plant material and the lower level of GHG reductions. In relation to differences between plant sizes

results indicate that costs are lower for farm level plants than for joint biogas plants.

The sensitivity of the results to changes in the assumptions underlying the calculations of changes in GHG emissions is investigated by recalculating the scenarios based on different GHG emissions coefficients. The results of these sensitivity analyses show that the results appear particularly sensitive to changes in the emissions coefficients for N_2O, and especially so for the scenarios involving plant material as an input. Based on the applied minimum and maximum values for the GHG emissions coefficients the consequences of changing the emissions coefficients for CH_4 and the soil Carbon content are significantly less pronounced.

Sensitivity analyses have also been accomplished for the large farm plant scenarios with regard to the assumed transport distances between suppliers of organic material and the biogas plant. However, even with a 50 % reduction in transport distances the analysed biogas technologies are still welfare economically unprofitable.

1 Introduction

The current Danish biogas production amounts to around 4 PJ, which is equivalent to around 0.5 % of the total energy consumption in Denmark (Tafdrup, 2009). While app. 50 % of the biogas production takes place at industrial facilities, wastewater treatment plants or rubbish dumps, the remaining app. 50 % is produced either on farm biogas plants or joint biogas plants where biogas production is based on manure, e.g. in combination with organic industrial waste (Jørgensen, 2009). The focus of the present study is on biogas production on farm biogas plants and joint biogas plants, where the input is manure and/or plant biomass.

By 2010 there were around 20 joint biogas plants and 60 farm biogas plants, which together processed around 5 % of the total production of manure/slurry (Landbrug og Fødevarer, 2011). Although this percentage appears quite low it may be noted that it in an international context actually is quite high With only around 5 % of total slurry production currently being used for biogas production there seems to be significant potential for expanding the production of biogas, and as an example it is in Fødevareministeriet (2008) found to be realistic that around 45 % of the total production of slurry/manure is used for biogas production by 2020. Biogas is considered to be a CO_2 neutral fuel and therefore substitution of fossil fuel based energy with energy from manure based biogas production contributes significantly to the abatement of GHG emissions. Due to this, expansion of biogas production is considered to represent a potentially important element in relation to Denmark's ability to meet the goals set out for its contribution to the mitigation of climate change.

Compared to many other countries Denmark has quite ambitious climate and energy policies. In Table 1.1 the more specific targets in terms of GHG reductions and renewable energy shares set at both the international, EU and national level are listed, and biogas production is expected to contribute to the fulfilment of all these targets. As it appears from the table, three different targets are set in terms of the share of renewable energy in total energy consumption. The deadline for fulfilment of one of these targets is 2011, where renewable energy should account for 20 % of gross energy consumption (Regeringen, 2008). Projections of Danish energy consumption made by the Danish Energy Authority show that the share of renewable energy in total energy consumption will amount to 21 % implying that the nationally set target is expected to be met. Of these 21 % in 2011, biogas accounts for approximately 3 % (Energistyrelsen, 2011). The deadline for the other two targets specifically related to renewable energy is 2020, where 30 % of total energy consumption and 10 % of energy used for transport should come from renewable sources (Klima – og Energiministeriet, 2011a). From the table it also appears that a nationally set target states that up to 50 % of livestock manure should be used for energy production by 2020 (Regeringen, 2009); the resulting energy production is subsequently expected to be around 18 PJ (Energistyrelsen, 2011). With reference to the official projections of Danish energy consumption, this implies that biogas production by 2020 may in fact account for 8,4 % of the required production of renewable energy in 2020. In this connection it may be added, that the contribution of manure based energy production to total production of renewable energy may be even greater than what can be produced in the form of biogas. Thus, while the common practice is to use the digested slurry for field application an alternative option is to separate the digested slurry, and subsequently use the liquid fraction for field application and combust the solid fraction, thereby increasing the amount of energy extracted from the manure.

Table 1.1 Political targets relevant for biogas production (Klima – og Energiministeriet 2011a; 2011b; Regeringen, 2009; 2008).

Internationally binding targets
• 30 % of energy consumption should come from renewable sources by 2020.
• 10 % of energy used for transport should come from renewable sources by 2020.
• 20 % reduction of GHG emissions from the sectors outside the EU ETS by 2020 (base year 2005; note that the target is raised to 30 % if an internationally binding agreement on GHG reductions is made).
• 21 % reduction in GHG emissions (average for the period 2008-2012; base year 1990).
National targets
• up to 50 % of livestock manure in Denmark should be used for green energy production by 2020.
• 20 % of gross energy consumption should come from renewable sources by 2011.

Although the production of biogas is well-defined in the sense that it refers to the production of biogas from organic materials, a range of different approaches – characterised by different input compositions, technologies and uses of output – to biogas production exists. The choice between different approaches affects the specific GHG (Greenhouse Gas emission) abatement potential of biogas production, the potential for expanding biogas production and the economic profitability of biogas production.

In terms of input to biogas production slurry/manure is normally co-digested with organic industrial waste. The reason for this being that the dry matter content of slurry/manure is too low to ensure the economic profitability of biogas production solely based on manure/slurry. Currently the addition of industrial waste, which serves to boost energy production, is therefore a prerequisite for the economic rentability of biogas production. However, as this type of waste represents a scarce resource, the availability of waste for co-digestion in effect represents a limiting factor in relation to expanding biogas production. In order to overcome the obstacles related to the limited availability of waste, research efforts, among others, focus on exploring the possibilities for substituting high energy waste products with fresh plant material. Also, focus is on developing technologies capable of increasing the biogas production per unit of slurry/manure; examples are separation of slurry and serial digestion.

1.1 Previous economic studies of biogas production

Several previous studies have analysed the economics of biogas production in Denmark; Table 1.2 gives a brief overview of the focus and conclusions of these previous studies. As it appears from the table, the production processes considered varies both in terms of input, treatments, capacity of biogas plants and use of output. Despite the variability in processes the conclusions drawn from the studies are quite similar in the sense that all studies find that either addition of waste or increasing the dry matter content of slurry/manure by separation is a prerequisite for biogas production to be welfare economically profitable. Thus, biogas production based solely on untreated manure or plant material is in all cases found to be prohibitively expensive, and this goes for the case where biogas is used for heat and electricity production as well as the case where biogas is upgraded to natural gas.

Table 1.2 Overview of existing economic studies of biogas production in Denmark.

Study	Characteristics of production process	Externalities considered	Notes and conclusions
Nielsen et al. (2002)	Input: Manure + 0-20 % organic waste. Treatment capacity: 300, 500, 800 m^3 per day. Use of biogas: CHP production at biogas production plant, sale to local CHP plant	GHG reduction. Recycling of organic waste. Reduced odour problems. Agriculturally related effects (changed storage/transport requirements, redistribution of phosphorous (?), improved utilisation of nutrients)	Financial profitability requires addition of waste and the presence of subsidies. Welfare economic profitability requires addition of waste.
Hjort-Gregersen (2003)	Empiric assessment of the economics of existing biogas production facilities.	n.a.	
Christensen et al. (2007)	Input: Manure (organic waste in baseline scenario). Treatment capacity: 400-700 m^3 pr day. Treatments considered: separation (before and after biogas production), recirculation of fibre fraction, serial digestion, wet oxidation or pressure cooking of plant material. In total 6 scenarios + baseline considered. Use of biogas: CHP production at biogas production plant, sale to local CHP plant	n.a.	Point of departure of the analysis is Nielsen et al. (2002). No new welfare economic calculations are made; welfare economic considerations based on Nielsen et al. (2002). Biogas production based solely on manure is not welfare economically profitable
Fødeva-reministeriet (2008)	Input: 1) Manure, 2) Manure + fibre fraction from separated manure, 3) Maize, 4) Grass from extensively managed areas. Treatment capacity: 300, 550, 800 tonnes per day. Use of biogas: CHP plant	GHG reduction. Reduced N-leaching. Increased fertilizer value of treated manure. Changes in soil carbon (?)	Point of departure of the analysis is Nielsen et al. (2002). Biogas production based on manure including separation is found to be a welfare economically relevant GHG abatement alternative, while biogas produced from maize or grass are found to be too expensive.
Dansk Gas-teknisk Center (2009)	Input: Manure + 11 % organic waste. Treatment capacity: 550 tonnes per day. Use of biogas: CPH plant, upgrading to natural gas, upgrading to fuel	GHG reduction. Recycling of organic waste. Reduced odour problems. Reduced costs related to transport and storage. Increased fertilizer value of treated manure. Reduced pollution of water resources	Point of departure of the analysis is Nielsen et al. (2002). Financial economic analysis based on case study. Welfare economic analysis based on theoretical facility. Welfare economic value of biogas only greater than that of natural gas if the value of waste recycling is included in the analysis.

This report contains financial as well as welfare economic analyses of biogas production in Denmark, and in many aspects the production processes considered are quite similar to the process subjected to analyses in the previous studies. However, the more specific input compositions considered in the present study are different than those previously considered. The analyses in the present study are also distinguished from previous analyses by considering fairly small-scale production plants and by specifically considering biogas production on organic farms. Finally, the analyses in the present study will, compared to previous studies, include more detailed assessments of the effects of biogas production on the agricultural greenhouse gas (GHG) balance. Hence sensitivity analyses, related to the effects of biogas production on the carbon content of the soil, CH_4 emissions and and N_2O emissions, are performed.

1.2 Specification of scenarios

In the present study focus is on biogas production based on different mixtures of slurry (cow and pig) and plant material (maize silage and grass clover), and the analyses are conducted at the level of individual production facilities.

The analyses consider three different model facilities; a decentralised production facility (i.e. farm biogas plant) with a treatment capacity of 50 tonnes per day and two centralised production facilities (i.e. joint biogas plants) with treatment capacities of 500 and 800 tonnes per day. The analyses focus on two different types of biogas plants in order to assess potential differences between farm biogas plants and joint biogas plants, which each are associated with their own advantages and disadvantages, and the background for working with two different plant sizes for the joint biogas plants is to see if economics of scale imply that there are significant benefits to be realised from increasing the processing capacity. In terms of the more specific choice of plant sizes, the processing capacity of 50 tonnes per day for the farm biogas plants has been chosen to reflect the size, which is considered most relevant in the future; hence it may be noted that it is a quite large facility compared to current farm biogas plants. For the joint biogas plants the more specific plant sizes has been chosen to reflect the sizes, which were considered most relevant in relation to the construction of new biogas production plants. In this connection it may however be noted that several biogas plants with significantly greater processing capacities are planned/under construction (Energistyrelsen, 2010b), suggesting that economics of scale are indeed a relevant parameter in relation to biogas production. In terms of the more specific technologies the considered process is fairly conventional in the sense that it does not include treatments such as separation, oxidation or serial digestion.

The produced biogas is used for the joint production of electricity and heat, which corresponds to the current use of biogas in Denmark. On the joint biogas plants, part of the produced biogas is used on-site for the production of heat – which is used as input in the production process - and electricity – which is sold; the remainder of the biogas is sold to local combined heat and power (CHP) plants. On the farm biogas plants the produced biogas is used on on-farm CHP installations. In both cases, the digested slurry/manure – and plant material, if added to the process – is subsequently returned to the farm, where it is applied to the field as fertilizer.

In relation to the use of biogas for CHP production, it may be noted that several actors in the biogas debate find it relevant, especially in relation to the proposed expansion of biogas production, to reconsider the current use of biogas, and instead let biogas enter into the natural gas distribution network. As it is now, it is possible to feed (upgraded) biogas into the natural gas distribution network, but the structure of the current tax/subsidy system makes this option irrelevant seen from a private economic perspective. Hence biogas fed into the natural gas distribution network is taxed equally to natural gas irrespective of the CO_2 neutrality of biogas, implying that once the biogas enters the gas system the tax system does not take account of the lower level of externalities associated with biogas compared to natural gas. However, restricting biogas to serve as an input to CHP production is associated with seasonal inefficiencies in energy use and it significantly limits the flexibility of biogas producers in terms of selling their product. In terms of market flexibility, current practices imply that biogas is transported from producer to user through pipelines established specifically for this purpose, and the costs associated with establishing this distribution network implies that it is not straightforward to establish new customer relations. Hence, most biogas plants are dependent on the demand from one – or at least very few – nearby CHP plants; this leaves them with very little market flexibility, and implies that they often find themselves in an economically very vulnerable situation. With respect to seasonal inefficiencies in energy use, these arise due to the inextricable link between the production of heat and electricity, which result from the use of biogas for CHP production. This implies that heat production cannot be turned off independently from the production of electricity, as it would have been desirable e.g. during the summer where the demand for heat is negligible. No doubt, this is a generic problem for CHP production; however, using other inputs for CHP production than biogas the problem can be dealt with by shutting down production when the demand for heat drops below the point where continued CHP production is economically optimal. Hence, production can be adjusted to ensure the efficiency of energy production/use. This option is, however, not available when using biogas for CHP production. Thus, biogas is produced continually, and storage capacity is usually low implying that CHP production has to be continuous, despite the fact that the energy efficiency of use at times will be very low; hence the alternative (i.e. shutting down production) would only imply an even greater waste of energy. Letting biogas be fed into the natural gas distribution network would eliminate the problems related to market flexibility and seasonal inefficiencies in energy use, and therefore this represents a relevant option in relation to improving the economic rentability of biogas production. However, there are also several potential problems/disadvantages associated with following this option; e.g. it would require biogas to be upgraded (which is associated with costs) and/or that appliances using natural gas are converted for a different – or perhaps varying – gas qualities. With this in mind, realisation of this option seems to require the adoption of a quite long time horizon and therefore it has not been included in the present analyses as such; however, it will be included as an important aspect in the discussions of the long term perspectives for expansion of biogas production.

As already mentioned we work with biogas production plants with 3 different biomass treatment capacities; namely, 50 tonnes per day, 500 tonnes per day and 800 tonnes per day. Where the 50 tonnes per day production plant is intended to reflect a large scale on farm production set up, the 500 and 800 tonnes per day plants represent joint production plants with two different capacities. Apart from working with three different plant capacities, we also work with five different input combinations; namely: 1) 100 % conventional pig slurry, 2) 75 % conventional pig slurry and 25 % conventional maize silage, 3) 100 % organic cow slurry, 4) 50 % organic cow slurry and 50 % organic grass clover, and 5) 100 % organic grass clover. The reason why we specifically distinguish between conventional and organic inputs is, that biogas often are mentioned as being particularly interesting in relation to organic agriculture, where the fertiliser value of the digested material is high due to the fact that the level of N-application within organic agriculture is constrained by the low availability of organic fertilisers. In terms of the conventional input combinations one might say that the 100 % pig slurry input is basically chosen as a point of reference for the 75 % pig slurry, 25 % maize input combination, since it seems to be widely accepted that biogas production solely based on slurry is not profitable today. Therefore most existing biogas plants are dependant on waste addition, which, however, will not be able to support a large expansion of the biogas sector, as waste resources are limited.. Hence, it is necessary to supplement slurry with an input with higher energy content, and here maize, which represents one of the currently most popular plant materials for biogas production, was considered the most relevant. Just as for pig slurry, 100 % cattle slurry is primarily chosen as the point of reference for the other two organic input combinations, and the reason for choosing grass clover as the plant input is that it is considered the most relevant when focus is on organic and environmentally friendly production practices. In relation to both pig and cattle slurry it should be noted that the dry matter content assumed in the present analyses are lower than what is conventionally assumed. Hence, the dry matter content is set to reflect the dry matter content experienced in practice rather than the norm based dry matter content. As biogas production per tonne of input increase with increasing dry matter content this implies that the biogas production per tonne of slurry in the present analyses is quite low and this has a negative effect in terms of the profitability of biogas production. However, it was deemed important to conduct the analyses based on realistic dry matter contents rather than hypothetical ones in order to secure the practical relevance of the results.

In combination, the three different plant facilities and five different input combinations result in 15 different scenarios for biogas production, which each are analysed separately. The scenarios are listed in Table 1.3.

Table 1.3 Scenarios analysed.

Scenario	Farm type	Input	Treatment capacity (tonnes pr day)	Plant type
1A	Conventional pig producer	100 % pig slurry	800	Joint
1B	Conventional pig producer	100 % pig slurry	500	Joint
1C	Conventional pig producer	100 % pig slurry	50	Farm
2A	Conventional pig producer	75 % pig slurry, 25 % maize silage	800	Joint
2B	Conventional pig producer	75 % pig slurry, 25 % maize silage	500	Joint
2C	Conventional pig producer	75 % pig slurry, 25 % maize silage	50	Farm
3A	Organic dairy producer	100 % cow slurry	800	Joint
3B	Organic dairy producer	100 % cow slurry	500	Joint
3C	Organic dairy producer	100 % cow slurry	50	Farm
4A	Organic dairy producer	50 % cow slurry, 50 % grass clover	800	Joint
4B	Organic dairy producer	50 % cow slurry, 50 % grass clover	500	Joint
4C	Organic dairy producer	50 % cow slurry, 50 % grass clover	50	Farm
5A	Organic dairy producer	100 % grass clover	800	Joint
5B	Organic dairy producer	100 % grass clover	500	Joint
5C	Organic dairy producer	100 % grass clover	50	Farm

As already mentioned, each of the 15 scenarios are analysed separately. There are many similarities across scenarios – e.g. depending on type of input or type of plant – and therefore many of the calculation principles and approaches are similar across scenarios. In order to avoid too many repetitions the basic principles and analyses approaches will only be thoroughly described in relation to one scenario. Hence, unless otherwise specified, the subsequent calculations will follow the previously described approaches.

In relation to the scenarios subjected to analysis it is important to note that they have not been defined with cost effectiveness considerations as the prime concern; that is, they have not been defined according to specific expectations regarding what is expected to be the most optimal scenarios seen from a welfare economic perspective. In stead the purpose of the analyses has been to estimate the welfare economic implications of the specified scenarios and the importance of including the value of the total GHG balance of the production and other externalities. The difference between these two approaches is important to bear in mind, especially in relation to the interpretation of the results. Hence, it should not be expected that the scenarios will result in low GHG reduction costs – i.e. be welfare economically optimal. The reasonability of such an assumption would require that cost-effectiveness considerations had played a prominent role in the definition of scenarios. In stead the results should probably best be interpreted as an illustration of the great variability in terms of the welfare economic value of biogas production, which suggests that the desirability of biogas production as a means to GHG reduction seen from a welfare economic point of view very much depends on the specific production approach.

1.3 Data

Investment and operating cost estimates used in the analyses are based on information provided by Petersen (2010) and Energinet.DK (2010). Data regarding changes in emissions are based on data from Energinet.DK (2010) (electricity) and Nielsen et al. (2010) (biogas and natural gas). Information on dry mater content in slurry and other agricultural assumptions are retrieved from Poulsen (2009), and from the project partners in the BIOMAN project.

Additional sources for data used in the calculations are referred to in the text throughout the report.

1.4 Structure of the report

The remainder of the report is structured as follows. Chapter 2 contains an introduction to socio-economic analyses, including both welfare economic analysis and financial economic analysis. This methodological chapter can be passed over if the reader is already familiar with socio-economic analysis or is mostly interested in the results of the analyses. Chapter 3 focuses on assessment of the value of biogas and finally chapters 4 through 18 contain detailed analyses of each of the 15 scenarios. In chapter 19 the results of the analyses are discussed, and finally, in chapter 20, a conclusion is presented.

2 Introduction to socio-economic analyses

Socio-economic analysis is a broad concept comprising several types of analyses. Therefore it is important to be specific about which type of analysis we mean when we talk about socio-economic analysis. In this report we distinguish between to types:

- Welfare economic analysis
- Financial analysis

The consequences of producing and using biogas in Denmark will be examined within the framework of these two analyses. The purpose and content of these will be explained below. A more complete description of the analyses can be found in Miljøstyrelsen (2010) (in Danish), Pearce & Nash (1981) and Johansson (1993).

The problem could also be analysed form a macroeconomic point of view where the focus is the consequences for Gross Domestic Product, employment, balance of payment, investments and consumption of introducing biogas. An analysis of these matters is not covered by this report. The problem of finding the most effective regulation of the biogas-sector so that all involved parties have the right stimuli to produce and use biogas in an optimal way will not be analysed either. The results of the financial analysis might be relevant for solving the regulation problem, but the report will not go further into this. The focus is the welfare economic and financial consequences of producing and using biogas.

2.1 Welfare economic analysis

The foundation of welfare economics is utility ethics that prescribe to choose the action that leads to the best consequences for persons' utility or welfare. What are the best consequences is determined by the sum of welfare generated and how it is distributed among persons. The utility ethical way of arguing assumes that utility or welfare is cardinally measurable and that utility can be compared between persons. This is also what is assumed within welfare economic analysis.

So, the purpose of welfare economic analysis is to calculate the consequences for persons' welfare of re-allocating the society's scarce resources. To build a biogas plant and produce biogas leads to use of scarce resources such as land, labour and real capital that could be used for producing other welfare generating products. The rise in the supply of biogas is a welfare gain to society but the use of resources in producing biogas is a loss.

As it is the consequences for persons' welfare that we want to calculate the two basic questions in welfare economic analysis are:

- Which consequences should be taken into account?
- How are the consequences going to be valued so that the values become indicators of changes in persons' welfare?

These two questions will be answered in the following.

2.1.1 The consequences which are included in welfare economic analysis

Fundamentally all consequences of a change in the society's resources - in the following called a project - that influence the welfare of persons should be taken into account in the welfare economic analysis. However this very general statement has to be further specified to be useful in practise. It has to be specified:

- The situation in relation to which the consequences are estimated - the basic situation
- What kind of consequences should be included in the analysis
- How the project is financed - change in dead weight loss
- The consequences for who - the geographical limits of the analysis.

The basic situation

As it is the consequences of a change in the use of resources that are evaluated it is of course very important to specify the situation in relation to which the change is defined. The result of the evaluation is absolutely dependent on the chosen basic situation and should always be interpreted in relation to that. In many cases the result will change if the basic situation is changed.

The basic situation also determine the question that is answered by the analysis and perhaps even more important which questions are answered. The analysis evaluate if the project leads to a welfare improvement or deterioration compared to the specified basic situation. It does not answer if there are other uses of the scarce resources that are better.

This is very important to remember when the results of the biogas analysis is presented and interpreted. Therefore the basic situation is described very thoroughly.

The consequences

In economic analysis it is normally assumed that the utility or welfare of a person depends on his consumption of goods and services. And here goods and services should be understood in a very wide sense. It is not just consumption of goods, which are sold in the market that influence a person's welfare but also consumption of a large number of so-called non-market goods. These comprise health goods, recreational possibilities, aesthetical values, cultural inheritance and so on. So when the consequences of a project are estimated the estimation should comprise the consequences for the supply all these different goods and services.

More precisely this means that the consequence description should comprise the following types of goods:

- Market goods
  - consumption goods
  - production factors (labour, real capital and land)
  - produced production goods (i.e. energy goods, chemicals and other raw materials)
- Non-market goods (depend on environmental loads)
  - health
  - recreational possibilities (angling, hunting, swimming, visiting nature and cultural sights etc.)
  - aesthetical values

A project might lead to an increase in the supply of one or more consumer goods - i.e. fruit, meat, computers. The production of these goods involves use of scarce production factors and produced production goods. Description of this resource use is an important part of the consequences description. Consumer goods as well as production factors and produced production good are all market goods, and therefore they can be valuated on the basis of their market prices - cf. Section 1.2.

Consumption and especially use of resources in the production process might have environmental consequences. These comprise first of all emissions to air, soil and water, but also physical load caused by i.e. changed land use (construction of roads or placing of wind turbines) and noise. However, the changed environmental loads do not always in themselves affect person's welfare. With regard to emissions we also need to know how the different matters are distributed in the environment, how the concentrations of matters change and how many persons are affected. The changed concentrations might both affect the productivity of production factors (fishing waters, land) and persons' health. To describe these consequences, which are the welfare relevant consequences it is necessary to know the connection between i.e. a change in particle concentration and risk of death. Connections like this are normally described by so-called dose response functions.

It is the welfare relevant consequences of changes in different environmental loads that should be valuated as a part of the welfare economic analysis. The valuation of these non-market goods is based on different direct and indirect valuation methods - cf. Section 1.2.

How the project is financed - change in dead weight loss

Often a project will have consequences for the public finances. If it is a public project it will involve public expenses and perhaps also public revenues. But, private projects might also affect public finances because of taxes and subsidies. If a renewable energy project results in saving fossil fuel on which is laid a tax the project will lead to a loss of tax income. Some renewable energy projects are also subsidized and if this is the case the project also means more public expenses.

If it is assumed that al other public activities - consumption, investments and income transfer - should be unaffected by the project new taxes have to be imposed. A tax increase will always lead to a loss to society because it represents a wedge between the marginal social benefit and cost of the good which is taxed. Without the tax the supply of the good would have been greater and the marginal benefits and costs would have been equal.

The loss to society of a tax is called the deadweight loss. It is an important part of the welfare economic analysis if the project has financial consequences for the public sector. Therefore, such consequences should be included in the description of the project's consequences. The financial consequences for the public sector will be analysed as a part of the financial analysis - see Section 2.2.

The consequences for who - the geographical limits of the analysis

In principle welfare consequences to all involved persons should be included in the welfare economic analysis - i.e. the geographical limits of the analysis should be the world. From a utility ethical perspective it does not matter if it is a native of Denmark or a foreigner who experiences a welfare change. So, all consequences that directly or indirectly affect persons whether they live in Denmark or elsewhere should be included in the welfare economic analysis. You ought to apply a global perspective of the analysis.

However, normally a national geographical limit is applied. The reason for this is that it is particularly difficult to know what will happen abroad when a project is carried out in Denmark. Of cause transboundary pollution from the project can be described, but what will happen to the economic activity and environmental load abroad if the project demands raw materials from other countries is not easy to anticipate. Also, It is not easy to valuate consequences for other countries because the accounting prices are often not known - cf. Section 1.2.

It is recommended always to describe transboundary pollution effects of a project if it has any. It also recommended to state if the project's import of inputs or substitution of an up till now imported good could have economic and environmental consequences for foreign countries. However, the consequences should not be valuated and included in the welfare economic analysis proper.

2.1.2 Valuation of consequences in welfare economic analysis

In welfare economic analysis the consequences of projects are valuated by use of so-called accounting prices (sometimes also called shadow prices). These prices are indicators of the marginal utility of each of consequences. Therefore, when the consequences of a project are valuated with accounting prices a quantitative measure of utility changes is calculated. The result of the calculation is an indicator of the sum of utility or welfare generated by the project. In the following the principles of determining accounting prices for market goods and non-market goods respectively are explained.

Market goods

A project might have consequences for the supply of consumer goods which can be bought in the market and normally a project uses input in form of production factors - labour, real capital and land - and produced production goods - e.g. energy goods and chemicals. It is the change in the supply and use of these goods that should be valuated and therefore accounting prices for each of these types of goods are needed.

Accounting prices of consumer goods are determined as equal to their consumer prices. If the consumers are assumed to maximize their utility the relative marginal utilities of the goods will be equal to their relative consumer prices. Therefore these prices can be used as indicators the marginal utilities to persons of different consumer goods.

Accounting prices of production factors should reflect the marginal opportunity costs of using these scarce factors in production. The opportunity costs are equal to the value of consumption, which the society has to give up when the scarce resources are drawn away from alternative use to be used in the project. If producers are assumed to maximize their profit, the factor prices (i.e. market prices exclusive taxes and subsidies) of the production factors will be equal their marginal value product to the producers. The factor prices reflect the value of the consumer goods, which are produced with the production factors - that is measured in factor prices, which are the prices that the producers get for the goods.

However, the relevant marginal value product in a welfare economic analysis should be measured in consumer prices. It is consumer prices, which are indicators of marginal utility. The consumer prices are equal to the factor prices increased with taxes and decreased with subsidies. Therefore, to calculate the production factors marginal value product in consumer prices their factor prices should be increased with the so-called net tax factor to get the production factors' accounting prices. These are equal to the value of consumption goods lost - the utility loss - when production factors are drawn away from alternative use.

Finally accounting prices of production goods, which are produced with production factor should be determined by calculating the production factor cost measured in accounting prices of producing the goods. This is the theoretically correct way to determine the accounting prices. However in practice two other methods are often used.

If the production good is internationally traded its accounting prices can be determined as its world market prices increased with the net tax factor. The argument goes like this: When an internationally trade good is imported it is paid for in foreign exchange which should be earned by exporting other goods. By exporting goods the society looses welfare corresponding to the inland value of the exported goods. The inland value is equal to the foreign exchange value increased with the net tax factor. So, the opportunity costs of importing a production good is a consumption loss equal in value to the import price increased with the net tax factor which is also the accounting price of the imported good.

For non-internationally traded production goods accounting prices are often determined as the factor prices of the goods increased with the net tax factor. The argument could either be the same as for the scarce production factors or an assumption that the factor prices of the producer goods are equal to the welfare economic costs of producing the good. Neither of these arguments is satisfactory, but in practice this way of determining the accounting prices is often the only possibility.

Non-market goods and external effects

For all market goods the accounting prices can be determined or calculated on the basis of market prices - consumer prices, factor prices or world prices. Such prices do not exist for non-market goods and among these environmental consequences of projects. Economists talk about external effects as these are not internalized in the market and therefore have no market prices.

The environmental consequences that should be valuated are the consequences which affect persons' living conditions or welfare - i.e. productivity or yield in primary sectors, health, recreational possibilities, ancient monuments and nature in itself. Economists distinguish between use values and non-use values.

Often it is only the environmental loads of a project - e.g. emissions to air and water and physical loads - that are directly known. To describe the ultimate consequences for persons' welfare it is necessary know how these consequences are connected with the loads. This involves knowledge of how matters are distributed in the environment, how this affect concentrations of matter, how many persons are affected by this and which type of nature is affected and finally knowledge about relations between concentration changes and production yield, health etc. - the so-called dose response relations. The description of these relationships is based on natural scientific and health scientific knowledge and models. It is a precondition of valuing the environmental consequences of projects that the relevant scientific knowledge exists.

If this is assumed, the consequences for the yield in primary industries - i.e. agriculture, forestry and fishery - can be valued on the basis of the change in the industries' production value measured in accounting prices. The products are sold in the market and therefore the change in the accounting price value of the production can be calculated on the basis of existing market prices - if necessary corrected for net taxes.

The accounting prices of all other environmental goods and consequences - i.e. health effects, noise, different recreational activities, cultural values and non-use values - must be valued in other ways. Fundamentally the accounting prices are determined on the basis of persons' willingness to pay for a change in the supply of the goods. This is analogous to determination of accounting prices for consumer goods. The consumer prices are equal to persons' marginal willingness to pay. So, all the different valuation methods which both include indirect methods based on actual prices of market goods and direct interview based methods in one way or the other reveal persons' willingness to pay for a change in supply of an environmental good.

However, sometimes an accounting price for an environmental load can be derived from the marginal welfare economic costs of reducing the load. This is the case when the society has a target for the reduction of this specific load. Examples for Denmark are CO_2 and NO_x emissions for which there are expressed specific reduction targets. In such cases it is possible to calculate the marginal welfare economic costs to society of meeting the target. This marginal cost is sometimes called the shadow price of meeting the target, and it can be used as an accounting price for the matter in question.

If a project implies an increase or decrease in the load of the matter it will mean more costs or saved costs respectively to meet the target. The shadow price of this specific matter reflects these costs. It is equal to the opportunity costs of having the target and might therefore be used as accounting price for changes in loadings of this matter. But, it is important to remember that shadow prices do not reflect the welfare gains of meeting environmental targets - i.e. the willingness to pay for these gains. Therefore shadow prices are not real accounting prices.

2.1.3 Discounting

Most projects last for more than one year. Therefore it is important to describe how the projects welfare economic gains and losses - benefits and costs - are distributed over time. However this causes one more problem. How should benefits and costs in different years be added?

In economic analysis this is done by discounting. Each year's net benefits are multiplied with a discount factor which value decreases over time with fixed rate per year. This rate is called the discount rate and for Denmark the Ministry of Finance has fixed its value to *6 percent*. - cf. Finansministeriet (1999). However, most Danish economists agree that this rate is too high.

By discounting future net benefits are ascribed a lesser value to society than actual net benefit. For this is given the ground that future people will be richer than actual people and therefore a given consumption change for them will be less valuable than for actual people. By discounting it is also evaluated if the projects rate of return is higher or less than the discount rate, which is assumed to reflect alternative return possibilities. If the project's net present value (the sum of the discounted net benefits in each year) is greater than zero its rate of return is higher than the alternative rate of return and the project is acceptable.

Sometimes it is not necessary to calculate the net present value of the project. This is the case if net benefits are expected to be constant over all future years. Here it is more relevant just to calculate the net benefits for one year. However, this gives rise to a problem regarding the distribution of the real capital costs over years of the capitals life time. A real capital good is normally purchased in one year, but it can be used over several years, and therefore the costs have to be distributed over these years to get the capital costs per year.

The annual capital costs are calculated by multiplying the purchase costs with the capital yield factor which depends on the economic life time of the capital and the discount rate. By this calculation the capital costs are distributed evenly over the life time of the capital and both depreciation and return on investment are accounted for.

2.2 Financial analysis

Financial analysis describes the income flows of a project - i.e. flows of money between the different actors who are involved in the project. The purpose of financial analysis is to indicate who are expected to be the economic winners and losers of the project if any and related to this who will have economic incentive to support the project and who will be against it. The results of the financial analysis can also form the basis of calculations of the necessary compensation to the losers or of changing prices, taxes or subsidies so that all the involved actors will have the same economic incentives to promote or reject the project.

Finally financial analysis is very important in uncovering any discrepancies between the project’s welfare economic profitability to society and its profitability to the economic actors - i.e. households, industries and the public sector. For example if a project because of heavy subsidies is very profitable to industries but from a welfare economic point of view represents a loss to society this will be an important argument against these subsidies. And conversely if industries are shown to have no financial incentive to go on with a welfare economic profitable project the government might consider to subsidize the project.

As financial analysis only concerns money flows real consequences that are not traded on the market are not a part of the analysis. Therefore, compared to the welfare economic analysis all external effects and among these the environmental consequences of the project are leaved out of the financial analysis. The income from sale of the project’s products and the expenses to the purchase of production factors and produced inputs are of course a central part of the financial analysis. Other important income flows are payments of excise taxes, income tax, interests etc. and incomes in the form of subsidies, compensations and other transferences all of which are not included in welfare economic analysis. They are all income transfers which do not represent a reallocation of scarce resources and a welfare change to society, but only redistribute income between its members.

A project might have consequences for property value in an area. It could be a new road that means saving of travel time for the inhabitants in the area and therefore leads to an increase in house prices, or it could be the establishing a waste disposal installation that leads to a decrease in house prices around the installation. Such changes in property values do not represent a welfare change and they are not relevant in a welfare economic evaluation, but sometimes they can be used as indicators of the value of external effects - in the examples saved travel time and inconveniences from the waste disposal installation respectively.

However, even if changed property values do not give rise to an actual income flow they should be included in the financial analysis. This is due to property value changes represent a transfer of income between potential sellers and buyers of the property.

2.2.1 The elements of financial analysis

Based on the general introduction to financial analysis this should include the following income flows:

- Revenue from sale of products
- Expenses for production factors and produced production goods
- Excise taxes
- Income taxes and corporation taxes
- Subsidies
- Compensation payments
- Loans, interests and repayments
- Changes in property values

If a project generates products that are sold on the market the revenue from this sale should be included in the financial analysis as an income to the owner of the project. The owner can be either a private person or a public institution.

Of course the payment for the products is an expense to the buyers, but these are assumed to have a restricted budget and therefore their total expenses are not changed by buying the projects products. Except if the total income of the society is increased which could be the case if the project employs formerly unemployed labour - see the following.

The project's payments for use of production factors and produced production goods mean an expense to the owners of the project. The payment also represents an income to the sellers of the production factors and goods, but as the production factors are assumed to be scarce directly and indirectly they will be drawn away from alternative use. Therefore, the total income of neither the owners of these factors nor the producers of production goods will be changed. An exception might be labour which until now has been unemployed. This labour will experience a net increase in income corresponding to the difference between wage payments and unemployment benefits. The payment of unemployment benefits will decrease which means a saving to the public sector.

A project might have consequences for the public revenue from excise taxes. For example an energy project that saves coal or oil will mean a decrease in public revenue from energy and environmental taxes. The opposite will of course happen if the use of taxed energy products is increased. Sometimes it is also necessary to take into account the indirect consequences for the public finances of drawing scarce resources away from alternative use. Such consequences could be relevant if the tax burden on alternative use of the resources is different from the tax burden on activities accompanying the project. An example of this is when resources are transferred from the private sector to the public sector.

Income taxes and corporation taxes are of course expenses for the project owners and revenue for the public sector. In principle they should be included in the financial analysis, but normally are ignored. This is due to difficulties in calculating these taxes because they depend on the owners other economic circumstances, depreciation principles, regulations concerning permissible deductions from income etc. Often it is also assumed that the tax revenue from the projects use of resources is approximately equal to the revenue from alternative use.

Subsidies and compensation payments are revenues to the project owner and expenses to the public sector or EU. They are important parts of the financial analysis. Sometimes they might even be a precondition for private actors to accept or to go on with a project that for environmental reasons will be a net benefit to society. Without subsidies or compensation payments the project might mean a loss to private actors and the financial analysis will show this. Therefore the results of analysis also can be used to fix the size of subsidy or compensation to make the project profitable to private actors.

Normally interest payments and repayments are not included in the financial analysis. This is due to the financing of the project is normally not specified. But, if the project is financed by loans and the terms of the loans are specified interest payments and repayment should be a part of the financial analysis. These payments are important for how the profit of the project is distributed. For example if the project is financed by foreign loans a part of the profit will go to foreign actors.

Finally the financial analysis should also include possible changes in property values. Of course a change in property values is not an actual payment as the other elements of the financial analysis, but as mentioned earlier property value changes still represent a transfer of income between potential sellers and buyers of the property.

2.2.2 Distribution of economic revenues and expenses

Every payment or income transfer should always enter into the financial analysis as a revenue to one actor and an expense to another actor - a sort of double entree bookkeeping. In this way it becomes possible to sum up who are total financial winners and losers of the project.

Public sector, EU, industries, households

This information will show who from a financial point of view can be expected to support the project and will be against it. The result also states how much the losers should be compensated by the winners to make the project profitable for all involved actors. Compensations could be made directly or they could be made by lowering the prices that the losers pay for some of the winner's products or services.

Of course it is not necessarily the financial gain or loss alone which determines if an actor supports or rejects a project. It might have external effects - e.g. positive environmental effects - that compensate the losers. Therefore it is important that the financial analysis is supplemented by a so-called *stakeholder analysis* which shows how all the involved actors are affected by the different economic and environmental consequences of the project. The stakeholder analysis also comprises an evaluation if there should be other things than the project's consequences that could make actors support or reject the project. This could be things like considerations about justice or the desire to pursue specific political agendas.

3 Assessing the economic value of biogas

Production of biogas is based on an input of organic matter which is processed at a biogas plant. Besides organic matter the production process includes the biogas plant (investment costs), transport, use of labour, chemicals, water, electricity and resources for service and maintenance. The main product is biogas, and this biogas can either be sold, used for energy production at CHP on the biogas plant or a combination of the two. As already mentioned, the use of the produced biogas varies across scenarios in the present analyses. Hence, for joint biogas plants it is assumed that there is an onsite CHP dimensioned according to the process heat requirement of the plant; biogas in excess of what is used at the on-site CHP is sold and so is any excess electricity production. For farm biogas plants it is assumed that the entire biogas production is used for energy production at an on-site CHP; hence, the marketed products from the farm biogas scenarios are electricity and heat.

For the part of the biogas which is sold, it is assumed that the biogas replaces natural gas as fuel in a local gas-fired CHP plant. Therefore the value to society of biogas is equal to the value of the amount of natural gas which is assumed to be replaced. As natural gas is a fossil fuel substituting this with biogas, which by definition is considered to be CO_2 neutral, also means a decrease in CO_2 emissions which also has a value to society.

The electricity from the biogas plant has a value to society because it replaces other electricity production or import. Depending on how the replaced electricity is assumed to be produced, there might also be a CO_2 gain related to the produced electricity.

For the farm biogas plants heat is produced in excess of the requirements for process heat, and this implies that farm biogas plants will produce an amount of heat for sale. In many cases, however, it may be difficult to find interested buyers, and consequently, the value of a significant share of the produced heat may in many cases turn out to be zero. In the present analysis it is assumed that 30 % of the excess heat production is used, while the remaining 70 % is lost. For the joint biogas plants the heat production is, as already mentioned, dimensioned according to the process heat requirement of the facility and therefore there are no excess heat production. The value of the heat used in the process is set to zero in the analyses as it represents an intermediate input that does not replace any other energy production/use.

3.1 Taxes and subsidies relevant for biogas production

The economic profitability of biogas production is affected – either directly or indirectly - by a number of different tax and subsidy schemes. In the following, these taxes and subsidies will be described in the context of the implications they have in relation to determining the financial and welfare economic value of biogas.

Because of subsidies and taxes biogas also has a value to the local CHP plant in excess of the value of the replaced natural gas – cf. Energistyrelsen (2010a). First biogas based power production is subsidized with 0.414 DKK per kWh (2009). Second biogas based power production is exempt from CO_2 tax which means a tax exemption of 0.351 DKK per Nm^3 (2010) replaced natural gas. Finally natural gas used for heat production is taxed by a rate equal to 1.974 DKK per Nm^3 (2010) natural gas used for heat production. This amount is calculated as total natural gas consumption times heat efficiency of the CPH plant which is assumed to be 47 % and this amount is finally divided by 1.25. There is no tax on biogas used for heat production. Thus the CHP plant avoids paying natural gas tax equal to

$$1.974\ DKK/Nm^3 \cdot 0.47 \cdot \frac{1}{1.25} = 0.742\ DKK/Nm^3 \text{ natural gas replaced.}$$

While these subsidies and tax exemptions mean an extra income and expenditure saving to the CHP plant they result in increased expenditures and loss of income to the State. The total loss of the State has to be replaced by an increase in other taxes which cause a so-called dead weight loss to society.

Below the accounting prices and prices to be used in a welfare economic and financial calculation of the value of biogas is described respectively. The prices are based on Energistyrelsen (2010a).

3.1.1 Welfare economic value of biogas

Marketed amount of biogas replaces natural gas with a price equal to 44.6 DKK per GJ (2008-price level) which is equal to

$$44.6\ DKK/GJ \cdot 0.0396\ GJ/Nm^3 = 1.77\ DKK/Nm^3.$$

In a welfare economic calculation this price has to be increased with the so-called net tax factor equal to 1.17 – cf. Finansministeriet (1999) and Miljøministeriet (2010) – to get the welfare economic accounting price of natural gas equal to 2.07 DKK per Nm^3.

Marketed amount of electricity from the biogas plant has value based on a power price equal to the average Nord Pool price 0.301 DKK per kWh. This price includes cost of buying CO_2 quotas for power production. Therefore, when this price is used in welfare economic calculations it is assumed that power from the biogas plant will replace other power production that gives rise to CO_2 emissions, i.e. the value of marketed electricity from the biogas plant includes the value of a decrease in CO_2 emissions from replaced power production. To get the welfare economic power price the Nord Pool price has to be increased with the net tax factor 1,17 to get a welfare economic accounting price of electricity equal to 0.352 DKK per kWh.

When biogas replaces natural gas at a local CPH plant it means more expenditure in form of subsidies from the State and loss of tax income to the State – cf. above. The value of subsidies is calculated as the produced amount of electricity multiplied with 0.414 DKK per kWh (2009). The value of CO_2 tax exemption is calculated as 0.351 DKK per Nm^3 (2010) multiplied with the amount of natural gas replaced. Furthermore the CHP plant avoids paying natural gas tax for heat production equal to 0.742 DKK per Nm^3 multiplied with the amount of natural gas replaced. The sum of subsidies and loss of tax income is finally multiplied with the dead weight factor equal to 1.2 to get the value of total welfare loss to society of the increased expenditures and lost tax incomes for the State.

It may be noted from January 2010 a tax on NO_x emissions has been imposed on all fuels giving rise NO_x emissions, and from January 2011 a tax on CH_4 emissions has been imposed on natural gas and biogas used as fuel on certain engine types. In terms of the CH_4 tax, it is disregarded in the present analyses; hence, the analyses are based on 2009 prices, and in 2009 the tax did not apply. Moreover, since the CH_4 emissions from the engines at CHP facilities are assumed to be identical, the omission is not believed to have any significant effect on the results of the analyses. In terms of the tax on NO_x emissions it is not accounted for in the analyses; hence the analyses are based on 2009 prices, and in 2009 the tax did not apply. Moreover, it may be noted that tax which is set to 5,100 DKK per tonne in 2011 (for facilitites where NO_x emissions are measured) is not expected to have an important effect in relation to the overall results of the analyses. For more detailed information about the taxes on NO_x emissions and CH_4 emissions see Skat (2009) and Skat (2010).

3.1.2 Financial value of biogas

In the financial analysis it is necessary to distinguish the economic consequences for

- the biogas plant
- the local CHP plant

This is because the economies of these two plants are interdependent through the assumed price of biogas. A high biogas price will be an advantage to the biogas plant, but a disadvantage to the CHP plant and vice versa for a low biogas price.

Biogas plant

The expenditures and receipts of the biogas plant should be calculated in factor prices. The expenditures include investment costs and purchase of the necessary inputs in the production process – i.e. use of labour, chemicals, water and resources for service and maintenance. Heat and electricity are also important inputs, but they do not give rise to expenditures as they are produced at a small CHP unit which is a part the biogas plant. In fact there will be a surplus of power production which can be marketed and in this way represents a receipt for the biogas plant.

The transport of organic matter from the farmers to the plant and transport of residual product back again to the farmers might also influence the economy of the biogas plant. However, as a starting point for the financial calculations it is assumed that the transport costs are all paid by the farmers. The biogas plant gets the organic matter free of any costs. Of course this assumption can be changed which will affect the economy of both the biogas plant and the farmers.

The biogas plant gets receipts from the sale of surplus power and biogas. The electricity can be marketed a price equal to the average Nord Pool price *0.301 DKK per kWh*. The price of biogas is a price open to discussion between the biogas plant and the local CHP plant, which is assumed to buy the biogas. It can be assumed that the biogas price per GJ at least will be equal to the price per GJ natural gas replaced. This is because the replacement of natural gas with biogas means further income and expenditure savings to the CHP plant in excess of the saved natural gas costs – cf. above. The natural gas price (and minimum biogas price) is equal to *44.6 DKK per GJ* (2009-price level) which is equal to $44.6\ DKK/GJ \cdot 0.0396\ GJ/Nm^3 = 1.77\ DKK/Nm^3$.

CHP plant

On the one hand the local CHP plant saves expenditures equal to the value of the replaced natural gas *44.6 DKK per GJ* (2008-price level). On the other hand the plant has to buy biogas the price of which can be expected to be equal to at least the natural gas price.

The local CHP plant can pay a higher price for the biogas than the natural gas price because by replacing natural gas with biogas it will get a subsidy equal to 0.414 DKK per kWh (2009) biogas based power production. To this must be added the value of CO_2 tax exemption equal to 0.351 DKK per Nm^3 (2010) natural gas replaced. Finally the CHP plant avoids paying natural gas tax for heat production equal to 0.742 DKK per Nm^3 natural gas replaced.

All other expenditures and receipts of the CHP plant is assumed to be unaffected by the replacement of natural gas with biogas as fuel.

3.1.3 Investment cost subsidy

One element of the Danish Governments strategy for Green Growth - cf. Regeringen (2009) - which was launched in 2008/9, is a subsidy scheme, according to which 20 % of the investment costs associated with the construction of new biogas plants (which need to satisfy a number of more specific criteria) are covered by a state financed subsidy. The 20 % investment cost subsidy applies to all joint biogas plants - whether based on inputs from organic or conventional farms – and to organic farm biogas plants, but not to farm biogas plants based on conventionally produced inputs. Moreover, there is an upper limit to the size of the subsidy; hence, the maximum size of the subsidy that can be granted for a single project is 30,000,000 DKK. Finally, granting of the subsidy requires that for biogas plants based on inputs from conventional agriculture at least 75 % (vol.) of the input has to be in the form of manure/slurry, while for biogas plants based on inputs from organic agriculture the minimum requirement is 50 %.

4 Scenario 1A: Biogas production from 100 % conventional pig slurry at 800 tonnes per day plant

Scenario 1A biogas refers to the situation where biogas production takes place at a joint biogas plant with a processing capacity of 800 tonnes per day, and where pig slurry constitute 100 % of the input. It is assumed that the slurry is obtained from slaughter pigs.

A daily input of 800 tonnes is equivalent to an annual input of 292.000 tonnes. According to Poulsen (2009) the norm dry matter content of pig slurry is 6.6 % and annual slurry production per slaughter pig is 0.47 tonne. In practice, the dry matter content of slurry is often found to be lower than the norm, and therefore it is chosen to operate with a dry matter content of 4.5 % in the present analyses. Adjusting the slurry production per slaughter pig for lower dry matter content the slurry production per slaughter pig is assumed to be 0.69 tonne which implies that 417,143 slaughter pigs are needed to produce the required amount of slurry. Using that one Livestock Unit (LU) is equivalent to 36 slaughter pigs this translates into 11,767 LU per biogas plant.

In the scenario it is assumed that the slurry is supplied by a number of farms and that the treated slurry is returned to the same farms where it is applied to the fields as fertiliser. Tank trucks with a capacity of 30 tonnes are used for the transport of both the untreated and the treated slurry. Hence, seen from the perspective of the farms the basic difference between the reference scenario and the biogas scenario is that they apply treated slurry instead of untreated slurry on their fields. In terms of the more specific transport requirements then it is assumed that the average distance between the farms and the biogas plant is 15 km. Moreover, it is assumed that it is possible to drive with return loads implying that inefficiencies are avoided.

The biogas treatment of slurry affects the properties of the slurry and this give rise to a number of agriculturally related effects, namely a reduction in the need for application of synthetic fertiliser and a subsequent reduction in N-leaching. Moreover, it also gives rise to changes in the emissions of CH_4 and N_2O just as it has implications in relation to the C-content of the soil - cf. Birkmose & Petersen 2004 and personal communication with BIOMAN project members.

In terms of the biogas production, it is assumed that part of the produced gas is used in connection with the biogas production. This production process needs first of all heat, but also some electricity both of which are assumed to be delivered from an on-site CHP plant. The surplus electricity production contributes to society's total electricity supply. The biogas which is not used for heat production at the biogas plant is sold to a local CHP plant where it replaces natural gas as fuel.

Below the real consequences of the whole production process is described and after this a welfare economic and financial analysis is performed respectively.

4.1 Consequence description

In Table 4.1 the consequences of biogas production from 100 % pig slurry at a biogas plant with a treatment capacity of 800 tonnes per day are summarized. The table is divided in three parts covering economic conse quences, emissions and taxes and subsidies respectively. Economic consequences include the consequences for production and use of material input of reallocating society's scarce resources. Emissions include the consequences for the discharge of different matters into the environment of the resource reallocation.

Table 4.1 Calculated Consequences of biogas production from 100 % pig slurry at biogas plant with a treatment capacity of 800 tonnes per day.

Economic consequences				Consequence per year
Agriculture				
- reduced demand for synthetic fertilizer				115 tonnes
Transport				
- slurry to biogas plant and - residual product to farmers				292.000 km
Biogas plant				
- biogas production for sale				1,332,719 Nm^3 natural gas equivalents
- electricity production for sale				5,876,770 kWh
- investment costs				72.5 M DKK (total amount)
- labour				2 persons' work
- electricity consumption				1,606,000 kWh
- water consumption				1,000 m^3
- chemicals				25,000 DKK
- service and maintenance				2,345,000 DKK
Emission consequences	Total, tonnes	Agriculture, tonnes	Biogas, tonnes	Transport, tonnes
- CO_2 emissions	- 4,677.684		- 4,913.652	235.968
- N_2O emissions	- 8.881	- 9.000	0.111	0.009
- CH_4 emissions	- 243.171	- 262.800	19.641	0.012
- C content of soil	- 591.300	- 591.300		
- particle emissions	0.202		0.174	0.028
- NO_x emissions	14.375		12.618	1.757
- SO_2 emissions	1.609		1.607	0.002
- CO emissions	29.381		29.098	0.283
- NMVOC emissions	- 3.926		- 3.970	0.044
- N-leaching	- 36.9	- 36.9		
Taxes and subsidies				
Biogas plant				
- construction subsidy (20 %)				14.5 M DKK. (total amount)
CHP plant				
- biogas based power production (subsidy)				2,410,090 DKK
- CO_2 tax exemption				467,784 DKK
- exemption from tax on natural gas for heat production				988,877 DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in dkk are stated in 2009 prices.. The emission consequences are to be interpreted as reductions in the emissisons from the current provision of energy, which is substituted by biogas.

Finally changes in taxes and subsidies are shown in order to calculate the consequences for tax revenue and expenditures of the state. Taxes and subsidies also affect the financial analysis of the biogas plant and CHP plant which buys the biogas.

It is seen from Table 4.1 that the economic consequences include reduced demand for synthetic fertilizer in agriculture, transport of slurry and residual product between farmers and biogas plant and the use of inputs at the biogas plant to produce biogas and electricity.

Emission consequences include changes in climate gas emissions CO_2, N_2O and CH_4 which first of all are due to the replacement of natural gas with biogas at the local CHP plant. Contrary to natural gas biogas is regarded as a CO_2 neutral fuel. In addition to this climate gas emission changes can both be related to changed production practice in agriculture and to changes in energy use within transport and biogas production. The change in C content of soil which also has a climate effect is related to changes in production practice in agriculture. Particle, NO_x, SO_2 and NMVOC emission changes are all related to changes in energy use within transport, biogas and power and heat production. Finally the consequences for N-leaching are due to a decrease in the use synthetic fertilizer because the residual product from biogas production has a higher fertiliser value than untreated slurry (a higher N-utilisation rate).

Changes in tax payments and subsidies from the state can be attributed to a construction subsidy to the biogas plant and subsidies to biogas based power production. To this must be added that CHP plants are exempted for CO_2 tax when power and heat production are based on biogas in stead of natural gas and in this case they also avoid paying the tax on natural gas for heat production. Below the individual consequences are explained in more detail.

4.1.1 Economic consequences

Use of N in agriculture

The use of pig slurry for biogas production and the subsequent substitution of untreated slurry with treated slurry as fertiliser have several implications in the field. Operating in the context of conventional agriculture, as we do in scenario 1A, an important agricultural effect of using slurry for biogas production prior to field application is that it reduces the need for application of synthetic fertilizer.

The reduced need for application of synthetic fertiliser is caused by the fact that the biogas treatment of slurry implies that the ammonium share of total N in slurry is increased by about 10 %. This implies that the plant availability of N in the slurry is increased. More specifically the share of N available for plant uptake increases from 75 % to 85 % (Birkmose & Petersen, 2004). Consequently, for each 100 kg total N in the slurry the application of synthetic fertilizer can be reduced by 10 kg – i.e. the substitution of untreated with treated slurry implies that the application of synthetic fertilizer can be reduced by 10 % of the total N content of the slurry.

According to Poulsen (2009) total N per tonne of pig slurry is 5.77 kg for slurry with a norm dry matter content of 6.6 %. Adjusting this to reflect the practice-based slurry dry-matter content of 4.5 %, which is applied in the present analyses, total N per tonne of pig slurry is 3.93 kg. The annual amount of slurry treated in the biogas plant is 292,000 tonnes implying that the annual total amount of N in the treated slurry is 1,148 tonnes. Accordingly, the amount of synthetic fertilizer N can be reduced by 115 tonnes per year.

Transport

As mentioned in the beginning of this section tank trucks with a capacity of 30 tonnes are used for the transport of both the 292,000 tonnes untreated slurry and the same amount of treated slurry. It is further assumed that the average distance between the farms and the biogas plant is 15 km. Moreover, it is assumed that it is possible to drive with return loads implying that inefficiencies are avoided.

These assumptions mean that the total transport demand can be calculated as 292,000 tonnes $\cdot$ 2 : 30 tonnes $\cdot$15 km = 292,000 km.

In relation to the estimated need for transport it should be noted that the assumed distance of 15 km between the farm and the biogas plant may be argued to be greater than the distance that one actually would consider to transport slurry across. Hence, seen from this perspective 10 km would probably be more realistic seen from a cost perspective. However, in relation to determining the relevant distance it is also important to consider the likelihood that it will actually possible to obtain the necessary input within the given distance from the plant. The reason why we have chosen to apply a distance of 15 km is based on such considerations. More specifically, it is considered likely that it in many cases will be impossible to get sufficient input within 10 km from the biogas plant, and therefore it has been chosen to operate with a distance of 15 km.

Biogas plant

The dry matter (DM) content of the biomass used as input to biogas production affects the biogas production potential of the biomass; hence, all else equal, the biogas production potential increases with increasing DM content. In terms of the dry matter (DM) content of pig slurry, the norm is 6.6 %, but in the present analyses DM is set to 4.5 % in order to reflect the DM likely to occur in practice. This implies that the estimated production is less than the production which theoretically could be obtained. Hence, if the DM content of slurry could be increased towards the norm, then the production per tonne of input would be higher. The key factors used to calculate biogas production per tonne of pig slurry are listed in Table 4.2.

Table 4.2 Calculated biogas production per tonne of pig slurry input.

Dry matter (DM) content of pig slurry	4.5 %
Kg DM pr tonne pig slurry	45
VS/DM ratio [1]	0.8
Kg VS pr tonne pig slurry	36
Nm^3 CH_4 pr kg VS [1]	0.280
Nm^3 CH_4 pr tonne pig slurry	10.08
CH_4 content of biogas	60 %
Biogas production (Nm^3 pr tonne pig slurry)	16.8
Heating value CH_4 (lower; MJ pr Nm^3)	35.9
Heating value natural gas (lower; MJ pr Nm^3)	39.9
Ratio: Natural gas/CH_4	1.1
Production in natural gas equivalents (Nm^3 pr tonne pig slurry)	9.16

Sources: Own calculations based on data from the BIOMAN partners and data from E-nerginet.DK (2010) (electricity), Nielsen et al. (2010) (biogas and natural gas and Poulsen (2009)

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be de-composed.

The amount of biogas produced from a tonne of input depends on the time that the biomass is kept in the reactor (Hydraulic Retention Time = HRT;), and generally production is an increasing function of the HRT. In the present analyses the HRT is assumed to be 20 days for pig slurry when used at an 800 tonnes per day plant. This is a fairly short HRT, and it is possible, that the economic profitability of production could be improved by increasing the HRT. In this connection it should be noted that increasing the HRT requires increased reactor capacity which increases investment costs; hence increasing HRT does not necessarily improve the economic profitability of production. The choice of a HRT of 20 days reflects common practice and is based on information from the partners in the BIOMAN project.

As mentioned previously a daily biomass input of 800 tonnes is equivalent to an annual biomass input of 292,000 tonnes, and with reference to Table 4.2, where the gas production per tonne of pig slurry is seen to be equal to 9.16 Nm^3 natural gas equivalents, this implies that the gross annual production of the facility amounts to approximately 2,668,000 Nm^3 natural gas equivalents. Assuming that the lower heating value of natural gas is 39.6 MJ per Nm^3 - cf. Energistyrelsen (2010a) - this is equivalent to a gross annual production of approximately 105,652,000 MJ.

In Table 4.3 it is specified how the produced biogas is used. It can be seen form the table that of a total production of 2,668,349 Nm^3 natural gas equivalents biogas only about 50 % of it 1,332,719 Nm^3 (52,775,691 MJ) can be sold to a local CHP plant. The reason for this is the need of process heat for biogas production. The heat is assumed to be supplied from an on-plant CHP facility which uses biogas as fuel.

Table 4.3 Biogas production for sale.

Use	Share of gross production (%)	Share in relevant energy equivalents
Gross energy production	100	2,668,349 Nm^3 Natural gas eqv.
Process heat [1]	30	31,734,560 MJ
Electricity for sale [1]	20	5,876,770 kWh
Biogas for sale	50	1,332,719 Nm^3 natural gas eqv. / 52,775,691 MJ

Sources: Data from BIOMAN partners and from the sources mentioned in the chapter.
Note1. Process heat and electricity for sale is assumed to be produced at an on-site CHP facility.

This on-plant CHP facility is, as previously mentioned, dimensioned according to the process heat requirement related to the heating of the input material. The amount of energy necessary to cover the process heat requirement depends on 1) the amount of biomass to be heated, 2) the net heating requirement (difference between the temperature of the input biomass and the temperature in the reactor), 3) the degree of heat recirculation and 4) the degree of heat loss. The energy requirement for heating biomass is 4.18 MJ per tonne per degree and for a thermophilic process – as is assumed for the joint biogas plants – the net heating requirement is 40 degrees. Setting the degree of heat recirculation to 55 % and assuming a 20 % heat loss the resulting process heat requirement per tonne of input is 4.18 MJ per tonne per degree $\cdot$ 40 degrees $\cdot$ (1.2 – 0.55) = 108.68 MJ per tonnes, which corresponds to about 30 % of the gross production. For the 800 tonnes per day biogas plant the total annual amount of energy used for process heat is 108.68 MJ per tonne $\cdot$ 292,000 tonnes = 31,734,560 MJ

The energy used for process heating can be seen as an intermediate product that would neither have been produced nor consumed had it not been for the biogas production. In relation to calculation of the process heat requirement for the different scenarios it may be noted that the process heat requirement per tonne of input is constant across the different types of input whereas the share of gross production which is needed to cover the process heat requirement varies significantly with the type of input. This is the result of the fact that the energy production potential varies significantly across the different types of input considered.

The production of heat at the on-site CHP facility is associated with a joint production of electricity. The amount of electricity produced is calculated based on the assumption that the efficiency in electricity production is 40 %. This means that total electricity production can be calculated as (Process heat production: 0.6) $\cdot$ 0.4 = (31,734,560 MJ : 0.6) $\cdot$ 0.4 = 21,156,373 MJ = 5,876,770 kWh as 1 kWh = 3.6 MJ. This result is shown in Table 4.3 and it corresponds to 20 % of the gross energy production.

The investment and operating cost estimates used in the analyses are based on information provided by Petersen (2010) and adjusted to fit the specific datails of the scenarios analysed in the present study. The different parts of the total investment costs of 72.5 M DKK associated with a biogas plant with a treatment capacity of 800 tonnes of pig slurry per day are seen in Table 4.4. The investment costs very much depend on the specific technical details of the facility, the geographical location of the facility and the preferences of the owner. Hence, the cost estimates presented in Table 4.4 should not be interpreted as exact cost, but rather as qualified estimate of the likely magnitude of the investment costs. It should be noted that costs associated with establishment of a 3 km long gas pipeline from the biogas plant to the CHP plant has been included in the investment costs estimates. Construction of gas pipelines is assumed to cost around 700,000 DKK per km.

Table 4.4 Calculated investment costs for biogas plant with a capacity of 800 tonnes per day and 100 % pig slurry as input - M DKK, factor prices.

Buildings, roads, etc.	14.8
Reactors, pipes, etc.	17.8
Gas scrubbers	6.0
CRS (Control, Regulation , Supervision system)	15.2
Pumps etc.	6.3
CHP	3.9
Building site	3.0
Investment costs (A1)	*67.0*
Gas pipeline	2.1
Projecting/planning costs (5 % of A1)	3.4
Total investment costs	72.5

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

The costs also include the earlier mentioned on-site CHP facility to produce the necessary heat for biogas production. In terms of the CHP related investment costs it may be noted that the costs are for all joint biogas plant scenarios are based on a cost per MJ of 0.075 DKK. In order to produce the necessary amount of process heat the on-site CHP facility must have a processing capacity of approximately 52.000.000 MJ, and this leads to an estimated CHP investment cost of 3.9 M. DKK for biogas plants with a daily input capacity of 800 tonnes. It is anticipated that the eectricity production from the on-plant CHP facility is sold.

As it appears from Table 4.1 operating the biogas plant is assumed to include the employment of two skilled workmen. In addition to this 1,606,000 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 1,000 m^3 water. Also different chemicals are needed with factor price value equal to 25,000 DKK. Finally annual service and maintenance costs are set to 3.5 % of A1 in Table 4.4, i.e. 67,000,000 DKK $\cdot$ 0.035 = 2,345,000 DKK.

4.1.2 Emission consequences

The total emission consequences stated in Table 4.1 are the result of the resource re-allocations described in Section 4.1.1 and like these they can be related to agriculture, transport and biogas production and use respectively. The consequences of these three activities are summarized in Table 4.5.

Table 4.5 Calculated emission consequences of biogas production from 100 % pig slurry at biogas plant with a treatment capacity of 800 tonnes per day - tonnes.

Activities	CO_2	N_2O	CH_4	C content of soil	Particles	NO_x	SO_2	CO	NMVOC	N-leaching
Agriculture		- 9.000	- 262.800	- 591.300						-36.9
Transport	235.968	0.009	0.012		0.028	1.757	0.002	0.283	0.044	
Biogas production and use	- 4,913.652	0.111	19.641		0.174	12.618	1.607	29.098	- 3.970	
Total	- 4,677.684	- 8.881	- 243.171	- 591.300	0.202	14.375	1.609	29.381	- 3.926	-36.9

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Below the different emission changes are explained in more detail.

Emission consequences related to agriculture

Using slurry for biogas production entails changes in N_2O and CH_4 emissions from agriculture. In addition to this C content of the soil and N-leaching will be affected. It may be noted that using slurry for biogas production also has implications in relation to NH_3 emissions, but the effects are two sided. Thus, while the biogas treatment of slurry results in treated slurry having a higher ph than untreated slurry leading to an increase in NH_3 emissions during storage and field application, increased viscosity of treated slurry compared to untreated slurry serves to reduce NH_3 emissions during field application. In the analyses these opposite effects are assumed to cancel out implying that the net effect on NH_3 emissions of biogas production is assumed to be zero.

The organic matter content of treated slurry is lower than that of untreated slurry. A consequence of this is that N_2O emissions following field application are lower for treated slurry than they are for untreated slurry. For pig slurry applied to the field in April the N_2O-N emissions coefficients are set to 1 % of N in the slurry for treated slurry and 1.4 % for untreated slurry. Assuming the N content of slurry to be 3.93 kg per tonne – see Section 4.1.1 - the total N content of the annual slurry input of 292,000 tonnes amounts to 1,148 tonnes and the reduction in N_2O-N emissions is consequently equal to 4.6 tonnes. With reference to the atomic weights of N_2O-N and N_2O the conversion factor between the two is 44/28 and therefore, the estimated reduction in N_2O-N emissions is equivalent to a reduction in N_2O emissions of 7.2 tonnes.

N_2O emissions are also affected by the changed demand for synthetic fertiliser. More specifically N_2O-N emissions from the application of synthetic fertiliser are assumed to be equal to 1 % of the N-content of the fertiliser and consequently, a reduction in the application of synthetic fertiliser translates into a reduction in N_2O emissions. The annual reduction in the application of synthetic fertiliser is estimated to be 114.8 tonnes – see Section 4.1.1 – which means that the reduction in N_2O-N emissions can be calculated to be 1.15 tonnes. Again using the conversion factor of 44/28 between N_2O-N and N_2O the 1.15 tonnes N_2O-N reduction is equivalent to a reduction in N_2O emissions of 1.8 tonnes. Add to this the reduction from slurry of 7.2 tonnes total N_2O emissions are reduced by 9.0 tonnes. The calculation of changes in N_2O emissions is based on the emissions coefficients listed in Appendix I.

The handling and storage of slurry – treated as well as untreated - give rise to CH_4 emissions. However, the production of biogas which basically is concerned with extracting CH_4 from the slurry implies that CH_4 emissions from treated slurry are less than emissions from untreated slurry. More specifically for pig slurry biogas treatment reduces CH_4 emissions by 0.9 kg per tonne of slurry (Møller & Olsesen, 2011). Thus, in the present scenario where the annual input of slurry is 292,000 tonnes the resulting reduction in CH_4 emissions is 262.8 tonnes.

Production of biogas implies that carbon is extracted from the input material. Therefore the carbon content of treated slurry is lower than that of untreated slurry. Consequently, using slurry for biogas production prior to field application rather than just applying untreated slurry to the fields gives rise to a reduction in the carbon content of the soil. More specifically, the reduction in soil C resulting from biogas treatment of pig slurry is set to be 45 kg C per tonne of dry matter in the slurry (Coleman & Jenkinson, 1996; Sørensen, 1987; Olesen, 2011). This number is calculated on the basis of the assumption that the C content of the pig slurry is 50 %. Of this 60 % is converted into biogas and it is finally assumed that soil C is reduced by 15 % of the share of C that has been converted into biogas.

As already mentioned the dry matter content of pig slurry in the present analyses is set to 4.5 % which is equivalent to assuming an absolute dry matter (DM) content of 45 kg DM per tonne of slurry. With a total annual slurry input of 292,000 tonnes the total amount of dry matter in the slurry is 292,000 tonnes slurry 0.045 tonne DM per tonne slurry = 13,140 tonnes DM and the resulting reduction in soil-C can be calculated to be 13,140 tonnes DM $\cdot$ 0.045 tonne C per tonne DM = 591.3 tonnes C. The reduction is soil-C is tantamount to an increase in the CO_2 content of the atmosphere – see Section 4.2.2 below.

Provided that the improved plant availability of N in treated slurry lead to a reduction in the amount of synthetic fertiliser applied in the field the level of N-leaching will also be reduced as a result of substituting untreated slurry with treated slurry as fertiliser. The resulting reduction in N-leaching is estimated to be in the interval 3-6 kg N per ha when 140 kg total-N per ha is applied– cf. Birkmose and Petersen (2004). In the present analyses the reduction in N-leaching following reduced application of synthetic fertiliser is set to 4.5 kg per ha. In order to calculate the total reduction in N-leaching of the scenario, it is necessary to calculate the number of hectares on which synthetic fertiliser application is reduced. Using that the N-content of the pig slurry is 3.93 kg per tonne and assuming that the amount of N applied per hectare is 140 kg we get that the amount of slurry to be applied per hectare in order to attain the target level for N application is 140 kg N per ha : 3.93 kg N per tonne slurry = 35.6 tonnes slurry per ha. Dividing the total annual amount of slurry 292,000 tonnes used as input to biogas production with the amount of slurry 35.6 tonnes to be applied per hectare we get the number of hectares on which the treated slurry is applied - i.e. 8,202 ha. Assuming that the level of synthetic fertiliser application is reduced on the entire area fertilized with the treated slurry the resulting reduction in N-leaching is 0.0045 tonne N per ha $\cdot$ 8,202 ha = 36.9 tonnes N.

Emission consequences related to transport

Transport of slurry between the farm and the biogas plant also gives rise to emissions. The emissions are related to the diesel used as fuel in the lorries used to transport the slurry. In Table 4.6 the emissions coefficients related to lorry transport (28-32 tonnes lorries) are listed along with estimates of the emissions changes for the current scenario where the annual transport requirement is 292,000 km. As it appears from the table, emissions changes are assessed for CO_2, N_2O, CH_4, Particles, NO_x, SO_2, CO and NMVOC

Table 4.6 Calculated annual emissions from transport of slurry between farms and the biogas plant (292,000 km) - tonnes.

	CO_2	N_2O	CH_4	Particles	NO_x	SO_2	CO	NMVOC
Emissions coefficient (g pr GJ)	73,894.15	2.66	3.84	8.81	550.28	0.47	88.67	13.85
Emissions coefficient (g pr km)	808.11	0.03	0.04	0.01	6.02	0.00	0.97	0.15
Annual emissions	235.968	0.009	0.012	0.028	1.757	0.002	0.283	0.044.

Source: Changes in emissions are calculated based on emissions coefficients from Winther (2011). Emission coefficients in g pr km are calculated from the emissions coefficients in g pr GJ using that the net calorific value of diesel is 35.87 MJ pr liter and that lorries run 3.28 km pr litre of diesel – cf. Danish Technical University (2010).

It is seen from Table 4.5 that the emission changes due to transport of slurry are negligible compared to the emission changes related to biogas production and use.

Emissions consequences related to biogas production and use

Emissions changes resulting from the changes in biogas production and use encompass the same emissions to air as those related to agriculture and transport – i.e. CO_2, N_2O, CH_4, particles, NO_x, SO_2, CO and NMVOC emissions. In addition to these emissions which are all related to changes in use of fuel in connection with energy production there might also be emissions and obnoxious smells from handling the slurry. However, with regard to the emissions they can be assumed to be the same irrespective of slurry being brought directly to the fields or being brought back and forth to the biogas plant. With regard to smell from the plant it is assumed that everything is done to minimize inconveniences and that the plant is placed in a sufficient distance from residential quarters not to bother anybody.

Changes in emissions caused by changes in fuel consumption involve types of emission changes. First heat and power production based on biogas is the occasion of emissions. Biogas based heat and power occurs both at the on-site CHP plant and at the local CHP plant. Second power production at the on-site CHP plant can be assumed to replace power production at coal based central CHP plants which will reduce emissions from these. Finally emission changes are caused by biogas replacing natural gas at the local CHP plant.

The different emission changes are summarized in Table 4.7.

Table 4.7 Calculated emissions changes from the changes in energy production caused by the production of biogas from 100 % pig slurry at a joint biogas plant with a daily input capacity of 800 tonnes.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	Particles	NO_x	SO_2	CO	NMVOC
		EF (g pr MJ):	0.00	0.00	0.43	0.00	0.20	0.02	0.31	0.01
Biogas based CHP production	Total production (105,666,620 MJ)	Change (tonne)	0	0.169	45.859	0.278	21.345	2.029	32.757	1.057
Reduced production of electricity with coal as fuel	Net electricity sale from biogas plant (15,374,520MJ)	EF (g pr MJ):	124.72	0.00	0.05	0.00	0.10	0.03	0.04	0.01
		Change (tonne)	-1,917.576	-0.028	-0.833	-0.064	-1.602	-0.406	-0.598	-0.171
Reduced use of natural gas at local CHP	Biogas sold to local CHP (52,775,691 MJ)	EF (g pr MJ):	56.77	0.0006	0.48	0.00	0.14	0.00	0.06	0.09
		Change (tonne)	-2.996.076	-0.031	-25.385	-0.040	-7.125	-0.016	-3.061	-4.855
Total net change in emissions (tonne):			-4,913.652	0.111	19.641	0.174	12.618	1.607	29.098	-3.970

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity) and Nielsen et al. (2010) (biogas and natural gas).

From Table 4.7 it is seen that overall the production of biogas and the associated changes in fuel use in energy production entail net increases in the emissions of N_2O, CH_4, particles, NO_x, SO_2 and CO while it results in net reductions in the emissions of CO_2 and NMVOC.

In the calculation of emissions from biogas based CHP production it is assumed that identical emissions coefficients apply to the on-site CHP and the local CHP and therefore the resulting emission increases can be calculated based on the total amount of produced biogas. The decrease in emissions from coal based electricity production is based on the net amount of electricity production at the biogas plant - i.e. electricity production at the on-site CHP plant minus electricity consumption for use in biogas production.

In relation to CO_2 it may be noted that although CO_2 emissions from biogas based energy production are in fact 83.6 g per GJ the emissions coefficient is set to 0 in the analysis. The reason being that biogas by definition is considered to be a CO_2 neutral fuel. This explains the significant reduction in CO_2 emissions caused by replacing natural gas and coal with biogas as fuel in energy production. However, in this connection it is important to note that the seemingly significant reduction does not translate to an equivalent climate effect. Hence, extending the perspective to encompass the entire energy producing sector instead of restricting the focus on the production of biogas in isolation the construction of the EU ETS scheme implies that the reductions in CO_2 emissions realised by the production of biogas does not lead to a reduction in the overall level of CO_2 emissions but only to a redistribution of emissions among the different producers in the energy sector. The reason for this is, that the total level of emissions from the sectors covered by the scheme – i.e. the emissions ceiling - is determined by the number of quotas initially issued. Therefore, the total CO_2 emissions are unaffected by the production of biogas and the subsequent substitution of natural gas with biogas. In spite of this CO_2 emission decreases are counted as a benefit to society because substitution of natural gas with biogas represents a possible CO_2 emission reduction.

In relation to CH_4 emissions it may be noted that another source of CH_4 emissions is the engines used for CHP production. More specifically, CH_4

emissions from the biogas production is estimated to be somewhere between 1 and 2 % of the gross CH_4 production. However, this CH_4 slip is not unique to biogas engines. It applies equally to the running of natural gas based engines. Hence, the methane emissions resulting from the CHP facility does not represent a change compared to the reference and therefore they are not considered in the present analyses which are only concerned with changes induced by the production of biogas.

Finally, in relation to the emissions coefficients for biogas listed in Table 4.7 it should be emphasised that as they are based on emissions from currently operating biogas engines, many of which currently are subjected to no limit values. Therefore the stated coefficients are unlikely to properly reflect the emissions coefficient which will apply to biogas engines in the future when limit values are imposed on all engines. In fact the current legal requirements in terms of limit values for different emissions are much stricter for natural gas fired engines than they are for biogas fired engines. Hence, where limit values have been imposed on all natural gas fired engines since 2006 limit values only apply to biogas fired engines installed after 2006 and it is not until 2013 that all biogas engines are required to meet the limit values specified for biogas based CHP production. Hence, in the future the emission coefficients for biogas are expected to be lower then the ones listed in the table. However, because of lack of detailed information about the size of the emissions coefficients which are likely to prevail in the future it is the actual emissions coefficients that are used in the analyses in this report. In relation to the differences between emissions coefficients for natural gas and biogas it should also be noted that even after 2013 where binding emissions limits will apply to all CHP engines there are likely to be differences between the two; the reason being that at least some of the emissions limits imposed on biogas engines are more lenient that the corresponding limit values imposed on natural gas engines.

4.1.3 Taxes and subsidies

The production and use of biogas result in a re-allocation of society´s scarce resources which, as can be seen from Table 4.1, affects government finances.

First of all biogas production is subsidized directly with a subsidy of 20 pct. of the total investment cost of 72.5 M DKK. This means a governmental expenditure of 14.5 M DKK.

Secondly use of biogas at the local CHP plant is also subsidized in different ways which depends on the amount of power produced and amount of biogas replaced – see Section 3.1. The amount of biogas produced which replaces natural gas at the local CHP is equal to 1,332,719 Nm^3. It has a calorific value of 52,775,691 MJ. Assuming that the local CHP has an efficiency of power production of 40 pct. the annual electricity production is equal to 5,863,966 kWh – cf. Section 4.1.1.

Biogas based power production is subsidized with 0.411 DKK per kWh. So the production of 5,863,966 kWh increases government annual expenditures with 2,410,090 DKK. In addition to this the local CHP plant receives tax exemption from both CO_2 tax and from tax on natural gas replaced for heat production. The tax rates are equal to 0.351 DKK and 0.742 DKK per Nm^3 of natural gas replaced at the CHP plant respectively – cf. Section 3.1. So, the total value of tax exemption can be calculated as 1,332,719 Nm^3 (0.351 +

0.742) DKK per Nm^3 = 1,456,662 DKK. This amount of money means a loss of income to the government.

In total the government annual net expenditures are increased with 3,866,752 DKK to which is added the one-off construction subsidy of 14.5 M DKK. This amount is important for the welfare economic calculations, because it represents a so-called tax distortion loss. Of course, the subsidies and tax exemptions are also important for the financial calculations which inter alia show how the economic situation of biogas plant and local CHP plant is affected by the biogas production and use.

4.2 Welfare economic analysis

The welfare economic analysis analyses how the economic consequences, the changes in emissions and the change in governmental net income affects society´s welfare. The following analysis is made according to the guidelines in Miljøministeriet (2010).

The value of the different consequences of biogas production and use is evaluated by accounting prices which are indicators of the consequences' marginal utility to persons. In Table 4.8 consequences, accounting prices and welfare economic value of consequences are shown.

It is seen from the table the total annual welfare economic value of biogas production from 100 % pig slurry at a biogas plant with a treatment capacity of 800 tonnes per day is equal to - 6.45 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss 7.09 M DKK, - 1.59 M DKK and 0.95 M DKK are due to economic consequences, emission consequences and taxes and subsidies respectively. Especially transport and investment costs are important for the total result.

Subsidies and loss of taxes which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 0.95 M DKK to society. This is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases which are the occasion of so-called dead weight losses. The assumption of necessary tax increases to finance expenditures and tax losses is requested by the Danish Ministry of Finance in connection with welfare economic analyses, but the assumption can of be discussed – cf. Møller & Jensen (2004). Other financing possibilities which do not lead to dead weight losses are possible. If the financing problem is ignored production and use of biogas still lead to a welfare economic loss of 5.55 M DKK.

Table 4.8 Calculated welfare economic value of biogas production from 100 % pig slurry at a biogas plant with a treatment capacity of 800 tonnes per day – M DKK

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			-7.09
Agriculture			
- reduced demand for synthetic fertilizer	115 tonnes	7,500 DKK pr tonnes ·	1.01
Transport			
- slurry to biogas plant & residual product to farmers	292,000 km	15,22 DKK pr km	- 4.44
Biogas plant			
- biogas production for sale	1,332,719 Nm^3	1.8 DKK pr Nm^3 · 1.17	2.81
- electricity production for sale	5,876,770 kWh	0.46 DKK pr kWh · 1.17	3.16
- investment costs	4.46 M DKK	4.46 M DKK · 1.17	- 5.22
- labour	2 persons' work	320,000 DKK · 1.17	- 0.75
- electricity consumption	1,606,000 kWh	0.46 DKK pr kWh · 1.17	- 0.86
- water consumption	1,000 m^3	25 DKK pr m^3 · 1,17	- 0.03
- chemicals	25,000 DKK	25,000 DKK · 1.17	- 0.03
- service and maintenance	2,345,000 DKK	2,345,000 DKK · 1.17	- 2.74
Emission consequences			1.59
- CO_2 emissions [1]	- 4,677.684 + 1,917.576 tonnes	105 DKK pr tonne · 1.17	0.34
- N_2O emissions	- 8.881 tonnes	105 DKK pr tonne · 310 ·	0.34
- CH_4 emissions	- 243.171 tonnes	105 DKK pr tonne · 21 ·	0.63
- C content of soil	- 591.300 tonnes	105 DKK pr tonne · 3,67·	- 0.27
- particle emissions	0.202 tonnes		
- NO_x emissions	14.375 tonnes	55,000 DKK pr tonne	-0.79
- SO_2 emissions	1.609 tonnes	85,000 DKK pr tonne	-0.14
- CO emissions	29.381 tonnes		
- NMVOC emissions	- 3.926 tonnes		
- N-leaching	- 36.9 tonnes	40,000 DKK pr tonne	1.48
Public net income - tax distortion loss	- 4.76 M DKK	- 4.76 M DKK · 0,2	- 0.95
Total			- 6.45

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK pr kWh 1,17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 4,677.652 tonnes deducted reduced CO_2 emissions from alternative electricity production 1,917.576 tonnes.

The total annual amount of greenhouse gas emissions reductions, measured in CO_2 equivalents, is: 4,677.684 tonnes (coming from CO_2) + 2,753.11 tonnes (coming from N_2O) + 5,106.59 tonnes (coming from CH_4) – 2,170.1 tonnes (coming from changes in soil C) = 10,367.314 tonnes. The value of this climate gas emission reduction is equal to 1.27 M DKK, which primarily is due to biogas being regarded as a CO_2 neutral fuel. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 7.72 M DKK to obtain the indicated climate gas emission reduction. Compared with the total annual amount of greenhouse gas emissions reductions, which measured in CO_2 equivalents is 4,677.684 tonnes (coming from CO_2) + 2,753.11 tonnes (coming from N_2O) + 5,106.59 tonnes (coming from CH_4) – 2,170.1 tonnes (coming from changes in soil C) = 10,367 tonnes, this results in an implied price of GHG reductions of 745 DKK per tonne CO_2.

It is also seen from the table that the costs to society of reduced C content of soil and increased NO_x and SO_2 emissions (due to higher NO_x and SO_2 emission coefficients for biogas than for natural gas) almost correspond to the value of reduced climate gas emissions. Thus, from a welfare economic point of view biogas production at a 800 tonnes production plant based on 100 % pig slurry does not seem to favourable.

Below, the individual entries of the welfare economic account are explained in detail.

4.2.1 Value of economic consequences

Generally accounting prices of economic consequences are determined as their market price (exclusive of refundable taxes) multiplied with the net tax factor which is equal to 1.17. For explanation see Miljøministeriet (2010). For international traded goods as e.g. energy product it is the international market price that should be multiplied with the net tax factor.

Agriculture
The market price of synthetic fertilizer is stated in Videncentret for landbrug (2010a) as 7,500 DKK per tonne N. This price is multiplied with the net tax factor to get the accounting price of 8,775 DKK per tonne N. As 115 tonnes synthetic fertilizer is saved the total welfare economic value of this societal gain can be calculated to be 1.01 M DKK.

Transport
The costs associated with this increased transport need should ideally be calculated as the sum of the costs associated with buying and maintaining the necessary number of tank trucks, fuel costs and manpower costs. However, in the present study general transport economic unit costs provided by the Department of Transport at the Danish Technical University (DTU) is used as the base for the assessment of transport related costs. The average cost per kilometre is comprised by a distance-dependent component and a time-dependent component. The assessment of the time-dependent component is based on an estimate of the hourly costs for lorry transport delays in order to account for the cost associated with frequent loading and unloading the trucks. The welfare economic cost per hour for lorry transport delays is assessed to be 576 DKK per hour Danish Technical University (2010), which assuming an average speed of transport of 50 km per hour is equivalent to 11.52 DKK per km. The corresponding distance dependent welfare economic cost is set to 3.7 DKK per km Danish Technical University (2010). Accordingly, welfare economic costs per km for lorry transport becomes 15,22 DKK per km and total welfare economic costs for the 292,000 km transport becomes 4.44 M DKK.

Biogas plant
The value of biogas sold to a local CHP depends on the value of the displaced natural gas. The market price of natural gas is equal to 1.8 DKK per Nm^3 natural gas – cf. Section 3.1.1 and Energistyrelsen (2010a) – and the accounting price is calculated by multiplying the market price with the net tax factor. On the basis of this the total welfare economic value of 1,332,719 Nm^3 natural gas equivalent biogas produced can estimated to be 2.81 M DKK.

The accounting price of electricity 0.46 · 1.17 DKK per kWh is also fixed on the basis of the expected market price in Energistyrelsen (2010a) – cf. Section 3.1.1. The price is used both to calculate the gain to society of 3.16 M DKK from the power production at the on-plant CHP plant and the costs to society of the electricity consumption in connection with the biogas production. It should be noticed that the accounting price includes the costs of buying CO_2 quotas for electricity production. Therefore, the value of electricity production at the on-site CHP plant includes the value of reduced CO_2 emissions from alternative electricity production.

Total investment costs are equal to 72.5 M DKK. However, the welfare economic analysis is concentrated on annual costs, and as the biogas plant has an economic life time of many years there is a need for converting the total costs into annual costs. Here the method described in Miljøministeriet (2010) is used. The life time of the biogas plant is assumed to be 25 years and with a welfare economic discount rate of 4 pct. the total costs of 72.5 M DKK can be converted into an annuity of 4.46 M DKK. The annual welfare economic investment costs are calculated by increasing this annuity with the net tax factor.

The welfare economic labour costs are calculated on the assumption that running the plant requires two employees, each working 1.600 hours per year, and that their salary is 200 DKK per hour. The total annual wage costs of 640,000 M DKK are increased with the net tax factor to get the annual welfare economic costs of 0.75 M DKK.

The market price of water including not refundable taxes is assumed to be 25 DKK per m^3. Therefore, the annual welfare economic costs of water use can be calculated as 1.000 m^3 · 25 DKK per m^3 · 1.17 = 0.03 M DKK.

The expenditures on chemicals and service and maintenance are all estimated in market prices and therefore, the welfare economic value of these costs can be calculated as the expenditures multiplied with the net tax factor.

4.2.2 Value of emission consequences

Ideally, changes in CO_2 emissions and emissions of other greenhouse gasses should enter the welfare economic analysis with a value that reflects the consequences of these emission changes for the overall level of welfare in society. However, the fact that CO_2 emissions affect climate conditions globally implies that in practice it is impossible to assess the consequences, both in relation to the actual climate change effects and the more specific consequences for peoples' welfare of these changes. Therefore, valuation of CO_2 emission changes cannot be based on expected welfare related consequences. Instead, the shadow price approach to valuation mentioned in Section 2.1.2 can be used to get an estimate of the value of the change in emissions. Hence, as a national CO_2 emissions target has been set the marginal welfare economic cost associated with fulfilling this target – i.e. the CO_2 shadow price – can be used as an accounting price for CO_2 emissions changes in the welfare economic analyses. The rationale behind using shadow prices in welfare economic analyses is that in order to meet the target an increase in emissions will entail an extra cost to society equal to the shadow price, while a decrease in emissions will represent saved costs i.e. a benefit to society equal to the shadow price.

All sectors of society have to contribute to meeting the CO_2 emissions target. However, while some sectors are covered by a quota system others are not. For the sectors included in the quota system – e.g. the energy sector – the CO_2 target can be met by buying quotas. Accordingly, businesses within these sectors will never engage in investments with the purpose of reducing CO_2 emissions if the costs exceed the quota price. Therefore, the quota price multiplied by the net tax factor represents the welfare economic cost associated with meeting the CO_2 reduction target within these sectors. For the sectors not covered by the quota system – e.g. the transport sector – the primary means of meeting the target is to engage in actual CO_2 abatement activities/initiatives. However, they are also allowed the option to fulfil their reduction obligation through participation in joint implementation initiatives abroad. As this opportunity also applies to the sectors covered by the quota system, it can be argued that the marginal reduction costs associated with joint implementation initiatives – and thereby also the marginal reduction costs facing the sector not covered by the quota system – ought to be equal to the quota price. Following this line of argumentation we have in the present analyses chosen to use the quota price as the base for valuing CO_2 emissions reductions both within the sectors covered by the quota system and the sectors not covered by the system. With a current price of CO_2 quotas of 105 DKK per tonne – cf. Energistyrelsen (2010) - and a net tax factor of 1.17 the resulting welfare economic value of reduced CO_2 emissions becomes 125 DKK per tonne CO_2.

The extent to which this equalisation of marginal abatement costs across sectors will occur in practice is not well established. Accordingly the argumentation underlying the approach adopted in the present analyses can of course be questioned and perhaps particularly so, considering that Denmark has set specific targets regarding the share of renewable energy. Hence such targets affect the extent to which abatement costs can be expected to adjust smoothly across sectors. Ideally different CO_2 shadow prices therefore probably should be applied for the different sectors. However, within the limits of the present study it is not possible to attempt estimation of a CO_2 shadow price specifically for the sectors outside the quota system.

CH_4 (methane) and N_2O (laughing gas) are like CO_2 greenhouse gasses and therefore, they also represent a welfare economic value in relation to their effect on climate change. Presently, the EU ETS scheme only covers the emissions of CO_2, but despite this the value of changes in the emissions of the other two greenhouse gasses – i.e. CH_4 and N_2O – can also be assessed with reference to the price of CO_2 quotas. Hence, by multiplying the changes in N_2O and CH_4 emissions with their respective CO_2 equivalent factors (310 for N_2O and 21 for CH_4) and the CO_2 shadow prices the values of changes in N_2O and CH_4 emissions can be estimated.

Also the C content of soil can be translated into a change in the CO_2 content of the atmosphere. With reference to the atomic weights of carbon (12) and oxygen (16), the atomic weight of CO_2 is 44. Using this, the increase in atmospheric CO_2 following the reduction in soil-C can be calculated as 44/12 = 3.67 times the reduction in C content of soil. This means that the shadow price of changes in C content can be calculated as 105 DKK per tonne $\cdot$ 3.67. Remark, that contrary to the reductions in climate gas emissions which represent benefits to society the reduction in C content of soil means a cost to society as it increases the CO_2 content of air.

Where the welfare economic consequences of changes in the emissions of greenhouse gasses and C content of soil are of a global nature the consequences related to changes in emissions of particles, NO_x, SO_2, CO and NMVOC are geographically much more restricted. Therefore, the actual consequences depend on where the emissions occur, as this determines the areas and populations that are affected by the induced changes. This implies that the consequences associated with e.g. a 10 unit change in particle emissions are not uniform from place to place. Instead they vary from place to place depending e.g. on population density, topography and wind-regimes. Seen from a theoretical perspective detailed assessments of the welfare economic value of changes in emissions of particles, NO_x, SO_2, CO and NMVOC are therefore very complicated to conduct, and seen from a practical perspective the costs associated with such assessments are likely to be prohibitive. As an alternative to context specific value estimates of emissions changes general unit value estimates have been derived for some emissions, namely NO_x and SO_2.

The unit value estimates for NO_x and SO_2 emissions used to value emissions changes in the present study are those endorsed by the Danish Energy Authority, cf. Energistyrelsen (2010a) - and they are basically assumed to reflect the average welfare economic value of emissions changes. For NO_x the unit price is set to 55 DKK per tonne. For SO_2 there are two different unit value estimates; one for emissions in high population density areas (130 DKK per tonne) and one for emissions in low population density areas (85 DKK per tonne). In relation to emissions changes related to biogas production, as is the focus of the present study, it is assumed that most emissions will take place in rural areas, i.e. areas characterised by fairly low population densities. Hence, in the present study the unit value estimate for SO_2 emissions of 85 DKK per tonne will be applied.

The emission of particles (TSP) constitutes a health problem. Hence, the age adjusted probability of dying is assumed to increase/decrease by 5 % when the concentration of particles increases/decreases by 10 microgram per m^3. Consequently, a reduction in particle emissions represents a benefit to society, and vice versa for an increase in particle emissions. However, it is very difficult to assess the exact welfare economic value of changes in particle emissions. First of all, it requires that the emissions changes are geographically explicit and that they by the use of air-transport models can be translated into concentration changes. Provided that the concentration changes also are geographically explicit it is then possible to determine the population which will be affected by the emissions changes. Subsequently, the assumed relationship between particle concentration and probability of dying can be used to calculate how the survival curves of the affected population will be affected by the changes in particle concentration. Finally, provided that one has an estimate of the Value Of a Life Year (VOLY), it is possible to calculate an estimate of the welfare economic value of the changes in particle emissions - see e.g. Møller (2009) for different approaches to include VOLY in welfare economic assessments. In the present analyses it is not attempted to assess the value of changes in particle emissions, and unfortunately, no unit value estimates exists for changes in particle emissions. Hence, the value of particle emissions changes will not be included in the analyses.

There exists no unit values for CO and NMVOC emissions either and therefore, they cannot easily be included in welfare economic calculation. These emissions can be injurious to health, but it is assessed that the concentration changes which occur in this study are so small that they can be assumed to have no health effects.

Finally the welfare economic benefit of the reduction in N-leaching can be valued based on a shadow price of 40,000 DKK per tonne. This price reflects the mean costs of reducing N-leaching in Denmark in the years 2005 – 2009 – cf. Jacobsen et al. (2009) – and therefore, does not represent a real valuation of the environmental consequences of reducing N-leaching. It is not a real shadow price either. First, it reflects the mean cost of different measures which all decrease N-leaching, but not the marginal costs of fulfilling the present Danish target for reducing the leaching. In fact the analysed measures do not reduce N-leaching to an extent that will meet the target. Second, the calculated costs are financial costs and not the welfare economic costs which also include the value of other environmental effects connected with the measures. Therefore, the calculated positive value of reduced N-leaching first of all serves an illustrative purpose.

4.2.3 Public net income – tax distortion loss

The value of the consequences for public finances – i.e. the value of increases in public expenditures and losses of income – is calculated according to the request by the Danish Ministry of Finance. In Section 4.1.3 it was calculated that the public sector will loose annual tax income equal to 3.87 M DKK. To this must be added an investment subsidy of total 14.5 M DKK, which means an annual expenditure of 0.89 M DKK. This amount is calculated by annualizing the 14.5 M DKK over a period of 25 years with a social discount rate of 4 %. In total annual public net income will decrease with 4.76 M DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 0.95 M DKK.

4.3 Financial analysis

The purpose of the financial analysis is to describe how income and expenditures of different involved economic sectors are affected by the project. In this case where biogas production is based on pig slurry and biogas is sold to a local CHP plant the involved sectors are agriculture, the biogas plant, the local CHP plant and the state. Calculation of income and expenditure changes are all based on the actual prices which are paid or received per unit of each product. The value of emission is not included in the financial analysis as these consequences are not market good which are traded and by this result in income and expenditures for the involved economic sectors. In Table 4.9 it is shown how the financial circumstances of these sectors are affected.

It is seen from the table that the agricultural sector and the local CHP plant are economic winners while the biogas plant and the state both are losers. In this connection, however, it is of course important to note that, this result depends on the underlying assumptions about relative prices and about which sectors receive income and bear expenditure burden.

Table 4.9 Calculated financial consequences of biogas production from 100 % pig slurry at a biogas plant with a treatment capacity of 800 tonnes pr day - M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			0.86 M DKK
- reduced demand for synthetic fertilizer	115 tonnes	7,500 DKK pr tonne	0.86 M DKK
Biogas plant			- 1.77 M DKK
- biogas production for sale	1,332,719 Nm^3 natural gas	4.4 DKK pr Nm^3	5.86 M DKK
- electricity production for sale	5,876,770 kWh	0.772 DKK pr kWh	4.54 M DKK
- investment costs	5.35 M DKK		- 5.35 M DKK
- construction subsidy	1.07 M DKK		1.07 M DKK
- labour	2 persons' work	320,000 DKK	- 0.64 M DKK
- electricity consumption	1,606,000 kWh	0.65 DKK pr kWh	- 1.04 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 DKK	- 0.03 M DKK
- service and maintenance	2,345,000 DKK	2,345,000 DKK	- 2.35 M DKK
- transport of slurry and residual	292,000 km	13.00 DKK pr km	- 3.80 M DKK
Local CHP plant			0.38 M DKK
- saved expenses for natural gas	1,332,719 Nm^3 natural gas	1.782 DKK pr Nm^3	2.37 M DKK
- consumption of biogas	1,332,719 Nm^3 natural gas	4.4 DKK pr Nm^3	-5.86 M DKK
- biogas based power production	5,863,966 kWh	0.411 DKK pr kWh	2.41 M DKK
- CO_2 tax exemption	1,332,719 Nm^3 natural gas	0.351 DKK pr Nm^3	0.47 M DKK
- exemption from tax on natural gas for heat	1,332,719 Nm^3 natural gas	0.742 DKK pr Nm^3	0.99 M DKK
The state			- 4.94 M DKK
- construction subsidy	1.07 M DKK		- 1.07 M DKK
- biogas based power production	5,863,966 kWh	0.411 DKK pr kWh	- 2.41 M DKK
- CO_2 tax exemption	1,332,719 Nm^3 natural gas	0.351 DKK pr Nm^3	- 0.47 M DKK
- exemption from tax on natural gas for heat production	1,332,719 Nm^3 natural gas	0.742 DKK pr Nm^3	- 0.99 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

In the following section the financial calculations are explained in more detail.

4.3.1 Agriculture

It is seen from Table 4.9 that the agricultural sector annually saves expenses equal to 0.86 M DKK. The saving is due to the decreased need for synthetic fertilizer when slurry is replaced by residual matter from the biogas production as fertilizer. The price of synthetic fertilizer of 7,500 DKK per tonne is based on Videncentret for landbrug (2010a).

4.3.2 Biogas plant

The biogas plant is expected to get an annual net deficit of -1.77 M DKK. The prices used in the calculations are factor prices including not refunded taxes which were the basis for determination of accounting prices in the welfare economic analysis – cf. Section 4.2.1. Yet the price of transport of 13.00 DKK per km is obtained by dividing the welfare economic accounting price of 15.22 DKK per km by the net-tax factor of 1.17. The financial result for the biogas plant is based on four important assumptions of which the first two have been discussed above.

First the biogas plant pays for transport of slurry from farmers to biogas plant and residual matter from the biogas plant to farmers. Alternatively it could have been assumed that transport is totally or partly paid by farmers because they earn a profit due to the reduced need for synthetic fertilizer. As it appears from Table 4.9 transport related costs are very large implying that changes in relation to this may have a significant impact on results; potentially it may even change the result for the biogas plant from negative to positive.

Second the biogas plant gets a price for biogas (measured in natural gas equivalents). The price the biogas gets for the biogas is not fixed; hence it is determined from case to case through negotiations between the biogas plant and the local CHP plant. Hjort-Gregersen (2010) report prices received by 6 different biogas plants in 2009; the average price per Nm^3 biogas is 2.22 DKK which assuming a CH_4 content of 60 % is equivalent to a price per Nm^3 CH_4 of 3.7 DKK. This price is somewhat lower than the price used in Energistyrelsen (2010b) where a price per Nm^3 CH_4 of 4 DKK is applied. This price, however, is lower than the price which according to Energistyrelsen (2009) would result if the price of biogas is assessed on account of its potential to displace natural gas as a fuel in CHP production – i.e. the break-even price. In the present analyses the value of 4 DKK per Nm^3 CH_4 is applied, and adjusted to a price per Nm^3 natural gas equivalents the resulting price becomes 4.4 DKK per Nm^3[1]. As the applied price is lower than the break-even price it can be argued that the local CHP plant will be willing to pay a higher price for biogas than assumed. If this is the case a higher biogas price will of course increase the profit of the biogas plant and reduce the economic advantage for the local CHP plant. Thus, the biogas price is a decisive factor of the distribution of a potential financial profit of biogas production.

Third differences in the tax/subsidy structure for electricity produced by different inputs imply that a discrepancy arise between the price per kWh which the biogas plant have to pay for electricity 0.65 DKK per kWh and the price which it receives for electricity produced at the plant 0.772 DKK per kWh. This implies that it is economically rational for the plant to sell all the electricity produced at the on-site CHP and subsequently buy the amount of electricity required as input to the production. Seen from welfare economic perspective, where taxes and subsidies do not represent actual costs and benefits, but only reflect a redistribution of welfare, electricity has only one value. Hence, the cost associated with using electricity at the plant enters the welfare economic analyses as a reduction in the amount of electricity available for sale from the plant and is valued according to the accounting price of electricity – cf. Section 4.2.1.

Finally the annual investment costs of 5.35 M DKK are based on an assumption that the total investment costs of 72.5 M DKK should be amortized over the assumed economic life time of 25 years and an annual interest of 6 % be paid. From this annual expenditure can be deducted a subsidy of 20 % equal to 1.07 M DKK.

[1] The price per Nm^3 CH_4 is adjusted to a price per Nm^3 natural gas equivalents based on the following relationship: 1.1 Nm^3 CH_4 = 1 Nm3 natural gas equivalent.

4.3.3 Local CHP plant

Over all, the annual result for the CHP plant is seen to be positive, more specifically it is estimated to be 0.38 M DKK.

First of all, the financial circumstances of the CHP are affected by reduced expenses for buying natural gas and increased expenses for buying biogas.

In Section 4.1.3 it was explained that biogas based power and heat production at the local CHP plant are subsidized in different way. The amount of biogas produced which replaces natural gas at the local CHP is equal to 1,332,719 Nm^3. It has a calorific value of 52,775,691 MJ.

Assuming that the local CHP has an efficiency of power production of 40 % the annual electricity production is 5,863,966 kWh – cf. Section 4.1.3. Biogas based power production is subsidized with 0.411 DKK per kWh, which means that annually the local CHP plant will receive a subsidy of 2,410,090 DKK from the state.

In addition to this the local CHP plant receives tax exemption from both CO_2 tax and from tax on natural gas replaced for heat production. The tax rates are equal to 0.351 DKK and 0.742 DKK per Nm^3 of natural gas replaced at the CHP plant respectively – cf. Section 3.1 – and therefore, annually the local CHP plant will save tax expenditures of 467,784 DKK and 988,877 DKK respectively.

4.3.4 The State

The state has increasing expenditures because of the construction subsidy to the biogas plant and biogas based power production at the local CHP plant. In addition to this the state loses tax income from fertilizer tax, CO_2 tax and tax on natural gas for heat production. In total net expenditures of the state are increased with 4.94 M DKK.

5 Scenario 1B: Biogas production from 100 % conventional pig slurry at 500 tonnes per day plant

Scenario 1B is very similar to scenario 1A, the primary difference being the processing capacity of the biogas plant. Hence, in scenario 1B focus is on biogas production on a plant with a daily input of 500 tonnes, which is equivalent to an annual input of 182.500 tonnes. This implies that the plant requires input from 260,714 slaughter pigs, which is equal to 7,354 LU's. The mean size of Danish pig farm is equal to 258 LU's - cf. Statistics Denmark (Databank) - which means that almost 30 farms have to deliver slurry to the biogas plant.

The only other difference between scenarios 1A and 1B is the assumed average distance between the farms supplying the slurry and the biogas production plant; where it is assumed to be 15 km in scenario 1A it is only assumed to be 10 km in scenario 1B. Hence, as the required amount of slurry is less in scenario 1B than in scenario 1A it is assumed that it in this scenario will be possible to acquire a sufficient amount of slurry from farms located at a smaller distance from the plant than it will in scenario 1A.

5.1 Consequence description

Many of the changes induced by biogas production are directly proportional to the amount of input used for biogas production. For these directly input related factors, the changes induced by scenario 1B can be assessed by a simple downscaling of the changes estimated for scenario 1A; more specifically, the changes applying to scenario 1B can be obtained by multiplying the changes assessed for scenario 1A by 0.625 (i.e. 500 tonnes per day/800 tonnes per day = 0.625).

With reference to the consequences relevant for scenario 1B listed in Table 5.1, the only consequences which cannot be assessed by a simple downscaling of the corresponding values assessed in connection with scenario 1A is 1) the investment and operating costs related to the biogas plant, and 2) the transport related consequences (including transport related emissions). For the consequences, which can be assessed by simple downscaling, the relevant values for scenario 1B are simply listed in Table 5.1; for descriptions of the consequences and the approaches used to quantify them reference is made to Chapter 4. The transport related consequences and the investment and operating costs applying to scenario 1B are assessed in the following sections.

5.1.1 Economic consequences

Transport

As mentioned in the beginning of the chapter, the distance between the farm supplying the slurry and the biogas plant are assumed to be 10 km in scenario 1B. The reason that a shorter distance is assumed for the 500 tonnes per day plant compared to the 800 tonnes per day plant is, that it is assumed to be possible to obtain the required amount of slurry within a smaller radius from the biogas plant now that the required amount is less. As in scenario 1A tank trucks with a capacity of 30 tonnes are used for the transport of both the untreated slurry and the same amount of treated slurry. Moreover, it is assumed that it is possible to drive with return loads implying that inefficiencies are avoided.

With a total annual slurry input of 182,500 tonnes, this implies that the total transport demand is 182,500 tonnes 2 : 30 tonnes ·10 km = 121,667 km.

Table 5.1 Calculated consequences of biogas production from 100 % pig slurry at biogas plant with a treatment capacity of 500 tonnes day.

Economic consequences				Consequence per year
Agriculture				
- reduced demand for synthetic fertilizer				72 tonnes
Transport				
- slurry to biogas plant and - residual product to farmers				121,667 km
Biogas plant				
- biogas production for sale				832,949 Nm^3 natural gas equivalents
- electricity production for sale				3,672,981 kWh
- investment costs				53.3 M DKK (total amount)
- labour				1 persons' work
- electricity consumption				1,003,750 kWh
- water consumption				1,000 m^3
- chemicals				25,000 DKK
- service and maintenance				1,708,000 DKK
Emissions consequences	Total, tonnes	Agriculture, tonnes	Biogas, tonnes	Transport, tonnes
CO_2 emissions	-2,972.713		- 3,071.032	98.319
N_2O emissions	-5.552	- 5.625	0.069	0.004
CH_4 emissions	-151.969	- 164.250	12.276	0.005
C content of soil	- 369.563	- 369.5625		
particle emissions	0.120		0.109	0.012
NO_x emissions	8.6187		7.886	0.732
SO_2 emissions	1.005		1.004	0.001
CO emissions	18.3041		18.186	0.118
NMVOC emissions	- 2.4626		- 2.481	0.018
N-leaching	- 23.06	- 23.06		
Taxes and subsidies				
Biogas plant				
- construction subsidy (20 pct.)			10.7 M DKK (total amount)	
CHP plant				
- biogas based power production (subsidy)			1,506,306 DKK	
- CO_2 tax exemption			292,365 DKK	
- exemption from tax on natural gas for heat production			618,048 DKK	

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in DKK are stated in 2009 prices.

Biogas plant

As for scenario 1A the investment and operating cost estimates are based on information provided by Petersen (2010). As seen in Table 5.2 total investment costs amount to 53.3 M DKK. The table also specify the share of total costs which can be attributed to the different cost components. In relation to the costs associated with purchasing the on-plant CHP unit it may be noted that the investment cost has been calculated on the basis of the same costs per MJ as in scenario 1A, that is 0.075 DKK per MJ. Hence, based on a required processing capacity of around 33,000,000 MJ (determined by the process heat requirement of the biogas plant) the resulting CHP investment costs are estimated to 2.5 M DKK.

This approach to calculating CHP investment costs may imply that the CHP investment costs for the 500 tonnes per day biogas plant, in relative terms, is underestimated compared to the costs for the 800 tonnes per day biogas plant. Hence, all else equal, economics of scale imply that one may expect the costs per MJ for larger facilities to be lower than those for smaller facilities. However, due to lack of more specific information on the likely magnitude of the economics of scale effect we have chosen to operate with identical per unit costs for all joint biogas plants. Nevertheless it should be noted that this approach may introduce a bias in the analyses. However, this bias is not expected to have a significant impact on the results. In this connection it should also be emphasised, as also mentioned in relation to scenario 1A, that the investment costs very much depend on the specific technical details of the facility, the geographical location of the facility and the preferences of the owner. Hence, the cost estimates presented in Table 5.2 should not be interpreted as exact cost, but rather as qualified estimate of the likely magnitude of the investment costs, and in this context the more specific assumptions made regarding CHP investment costs are expected to play a fairly small role. In relation to investment costs it may also be noted that while the costs associated with acquiring a building site are somewhat lower for the 500 tonnes per day plant than for the 800 tonnes per day plant, the costs associated with the establishment of a gas pipeline are identical across the two scenarios scenario; hence, in both cases the biogas plant is assumed to be located 3 km from the local CHP.

Table 5.2 Calculated investment costs for biogas plant with a capacity of 500 tonnes per day and 100 % pig slurry as input - M DKK, factor prices.

Buildings, roads, etc.	11.5
Reactors, pipes, etc.	11.1
Gas scrubbers	4.7
CRS (Control, Regulation , Supervision system)	11.8
Pumps etc.	4.9
CHP	2.5
Building site	2.3
Investment costs (A1)	48.8
Gas pipeline (3 km; 0.7 M DKK. per km)	2.1
Projecting/planning costs (5 % of A1)	2.4
Total investment costs	53.3

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

In terms of operating costs it is seen in Table 5.1 that the 500 tonnes per day plant is expected to employ 1 person instead of the 2 persons employed at the 800 tonnes per day plant. Moreover, water consumption and use of chemicals are also assumed to be the same for the two different plant sizes. In contrast, electricity use and service and maintenance costs are somewhat lover for scenario 1B compared to scenario 1A; hence, annual electricity consumption is set to 1,003,750 kWh while annual service and maintenance costs are set to 3.5 % of A1 in Table 5.2, i.e 1,708,000 DKK.

5.1.2 Emission consequences

All emission consequences in this scenario are calculated by multiplying the consequences in scenario 1A with 0.625 except for the transport related consequences.

Emissions consequences related to transport

The transport related emissions consequences of scenario 1B are assessed in Table 5.3. The changes are estimated by multiplying the emissions coefficients with the change in the demand for transport of 121,667 km.

Table 5.3. Calculated annual emissions from transport of slurry between farms and the biogas plant (121,667 km) - tonnes.

	CO_2	N_2O	CH_4	Particles	NO_x	SO_2	CO	NMVOC
Emissions coefficient (g pr GJ)	73,894.15	2.66	3.84	8.81	550.28	0.47	88.67	13.85
Emissions coefficient (g pr km)	808.11	0.03	0.04	0.01	6.02	0.00	0.97	0.15
Annual emissions	98.319	0.004	0.005	0.012	0.732	0.001	0.118	0.018

Source: Changes in emissions are calculated based on emissions coefficients from Winther (2011). Emissioncoefficients in g per km are calculated from the emissions coefficients in g per GJ using that the net calorific value of diesel is 35.87 MJ per litre and that lorries run 3.28 km per litre of diesel – cf. Danish Technical University (2010).

5.2 Welfare economic analysis

In Table 5.4 the welfare economic consequences associated with biogas production according to scenario 1B, their accounting prices, and their resulting welfare economic value are listed. The approaches used in the calculations are similar to those used in scenario 1A; hence, for specification of the calculation principles, reference is made to Chapter 4. Here we solely present the results.

Table 5.4 Calculated welfare economic value of biogas production from 100 % pig slurry at a biogas plant with a treatment capacity of 500 tonnes pr day – M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 4.3
Agriculture			
- reduced demand for synthetic fertilizer	72 ton	7,500 DKK pr tonnes · 1,17	0.63
Transport			
- slurry to biogas plant and residual	121,667	15,22 DKK pr km	- 1.85
Biogas plant			
- biogas production for sale	832,949 Nm^3 natural gas equivalents	1.8 DKK pr Nm^3 · 1.17	1.75
- electricity production for sale	3,672,981 kWh	0.46 DKK pr kWh · 1.17	1.98
- investment costs	3.28 M DKK	3.28 M DKK · 1.17	- 3.84
- labour	1 persons' work	320,000 DKK · 1.17	- 0.37
- electricity consumption	1,003,750 kWh	0.46 DKK pr kWh · 1.17	- 0.54
- water consumption	1,000 m^3	25 DKK pr m^3 · 1,17	- 0.03
- chemicals	25,000 DKK	25,000 DKK · 1.17	- 0.03
- service and maintenance	1,708,000 DKK	1,708,000 DKK · 1.17	- 2.00
Emission consequences			1.01
- CO_2 emissions [1]	-2,972.713 + 1,198.485	105 DKK pr tonnes · 1.17	0.22
- N_2O emissions	-5.552 tonnes	105 DKK pr tonnes · 310· 1.17	0.21
- CH_4 emissions	-151.969 tonnes	105 DKK pr tonnes · 21 1.17	0.39
- C content of soil	- 369.563 tonnes	105 DKK pr tonnes · 3,67·	- 0.17
- particle emissions	0.120 tonnes		
- NO_x emissions	8.6187 tonnes	55,000 DKK pr tonnes	-0.47
- SO_2 emissions	1.005 tonnes	85,000 DKK pr tonnes	-0.09
- CO emissions	18.3041 tonnes		
- NMVOC emissions	- 2.4626 tonnes		
- N-leaching	- 23.06 tonnes	40,000 DKK pr tonnes	0.92
Public net income	- 3.08 M DKK [2]	- 3.08 M DKK · 0,2	- 0.62
Total			- 3.91

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK pr kWh · 1.17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences, i.e. a reduction of 2,972.713 tonnes corrected for CO_2 emissions from alternative electricity production 1,198.485 tonnes.

Note 2. The public net income is the sum of the annual expenditure which the investment subsidy represents plus the annual loss in tax income.

It is seen from the table the total annual welfare economic value of biogas production from 100 % pig slurry at a biogas plant with a treatment capacity of 500 tonnes pr day is equal to - 3.91 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss 4.3 M DKK, - 1.01 M DKK and 0.62 M DKK are due to economic consequences, emission consequences and taxes and subsidies respectively. Especially transport, investment costs and service and maintenance costs are important for the total result.

Subsidies and loss of taxes which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 0.62 M

DKK to society. This is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases which are the occasion of so-called dead weight losses. The assumption of necessary tax increases to finance expenditures and tax losses is requested by the Danish Ministry of Finance in connection with welfare economic analyses, but the assumption can of be discussed – cf. Møller & Jensen (2004). Other financing possibilities which do not lead to dead weight losses are possible. If the financing problem is ignored production and use of biogas still lead to a welfare economic loss of 3.29 M DKK.

The total annual amount of greenhouse gas emissions reductions, which measured in CO_2 equivalents is: 2,972.713 tonnes (coming from CO_2) + 1,721.120 tonnes (coming from N_2O) + 3,191.349 tonnes (coming from CH_4) – 1,356.296 tonnes (coming from changes in soil C) = 6,529 tonnes. The value of this reduction is equal to 0.80 M DKK, which primarily is due to biogas being regarded as a CO_2 neutral fuel. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 4.71 M DKK to obtain the indicated climate gas emission reduction. The resulting implied price of GHG reductions is 721 DKK per tonnes CO_2.

5.3 Financial analysis

In Table 5.5 the results of the financial analysis pertaining to scenario 1B are presented. As was the case for the welfare economic analysis, reference is made to Chapter 4 for a detailed description of the principles applied in the calculations.

It is seen from the table that based on the assumptions underlying the present analysis, the agricultural sector and the local CHP plant are economic winners while the biogas plant and the state both are losers.

Table 5.5 Calculated financial consequences of biogas production from 100 % pig slurry at a biogas plant with a treatment capacity of 500 tonnes pr day – M DKK.

	Consequence per year	Price	Income and expenditures, M DKK
Agriculture			0.54
- reduced demand for synthetic fertilizer	72 tonnes	7,500 DKK pr tonnes	0.54
Biogas plant			- 0.96
- biogas production for sale	832,949 Nm^3 natural gas	4.4 DKK pr Nm^3	3.66
- electricity production for sale	3,672,981 kWh	0.772 DKK pr kWh	2.84
- investment costs	3.93 M DKK		- 3.93
- construction subsidy	0.79 M DKK		0.79
- labour	1 persons' work	320,000 DKK	- 0.32
- electricity consumption	1,003,750 kWh	0.65 DKK pr kWh	- 0.65
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03
- chemicals	25,000 DKK	25,000 DKK	- 0.03
- service and maintenance	1,708,000 DKK	1,708,000 DKK	- 1.71
- transport of slurry and residual	121,667 km	13.00 DKK pr km	- 1.58
Local CHP plant			0.24
- saved expenses for natural gas	832,949 Nm^3 natural gas	1.782 DKK pr Nm^3	1.48
- consumption of biogas	832,949 Nm^3 natural gas	4.4 DKK pr Nm^3	- 3.66
- biogas based power production	3,664,979 kWh	0.411 DKK pr kWh	1.51
- CO_2 tax exemption	832,950 Nm^3 natural gas	0.351 DKK pr Nm^3	0.29
- exemption from tax on natural gas for heat	832,950 Nm^3 natural gas	0.742 DKK pr Nm^3	0.62
The state			- 3.21
- construction subsidy	0.79 M DKK		- 0.79
- biogas based power production	3,664,979 kWh	0.411 DKK pr kWh	- 1.51
- CO_2 tax exemption	832,950 Nm^3 natural gas	0.351 DKK pr Nm^3	- 0.29
- exemption from tax on natural gas for heat production	832,950 Nm^3 natural gas	0.742 DKK pr Nm^3	- 0.62

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

6 Scenario 1C: Biogas production from 100 % conventional pig slurry at 50 tonnes per day plant

Scenario 1C is similar to scenarios 1A and 1B in terms of the type of input used for biogas production; hence, pig slurry constitutes the sole biomass input. In contrast to scenarios 1A and 1B which both are concerned with joint biogas plants, scenario 1C refers to the situation where biogas production takes place at a farm biogas plant with a daily processing capacity of 50 tonnes (equivalent to 18,250 tonnes per year). The annual input requirement of 18,250 tonnes is equivalent to the amount of slurry produced by 26,071 slaughter pigs (735 LU'S) implying that scenario 1C – at least compared to the size of currently operating farm biogas units – represents a quite large farm level production plant. Considering a facility of this size, however, is considered relevant in relation to investigating the future potential for farm level installations. In this connection it may be noted that facilities of the considered size could be established as joint ventures between two or three nearby farms rather than by one single farm.

As the biogas production takes place on the farm there is – compared to the reference scenario – no additional transport requirement associated with the biogas production. Hence, compared to scenario 1A and 1B, scenario 1C does not give rise to increased transport costs and increased transport related emissions. Another important difference between scenario 1C and the joint plant scenarios concerns the assumptions made in relation to how the produced biogas is used. The farm level biogas plant is assumed to be equipped with an on-site CHP unit dimensioned according to the amount of biogas produced at the plant. Hence, the entire production of biogas is assumed to be used on the on-site CHP, implying that no gas is sold from the plant and subsequently, that no substitution of natural gas with biogas occurs within decentralised CHP production.

All electricity production from the on-site CHP is sold while only part of the produced heat is used as process heat, implying that an amount of heat is available for alternative use. Part of this excess heat production is used for heating on the farm (e.g. stables and private residence) and it is assumed that this heat displaces previous oil based heat production. More specifically, it is assumed that 30 % of the excess heat production is used on the farm, while the remaining 70 % of the excess heat is lost. Hence, the costs associated with constructing the proper infrastructure for transporting the heat to alternative places of use are prohibitive, implying that it is not economically rational to engage in such investments, and consequently a large proportion of the heat production goes unused and represents no economic value.

The agriculturally related effects of scenario 1C are similar to those of scenario 1A and 1B, only the scale is different due to the smaller treatment capacity of the facility.

In terms of emission changes, the fact that the biogas plant is located on the farm implies that there are no transport related emissions associated with scenario 1C. Instead emissions changes are induced by the changes in energy production related to the increased production of heat and electricity from biogas at the on-site CHP and the subsequent displacement of other electricity production and oil based heat production.

6.1 Consequence description

Many of the changes induced by biogas production are directly proportional to the amount of input used for biogas production. For these directly input related factors the changes induced by scenario 1C can be assessed by a simple downscaling of the changes estimated for scenario 1A and 1B. In other cases the situation pertaining to the farm biogas plant differs from that of the joint biogas plants and subsequently the consequences and the way to assess them also differs in some instances.

Table 6.1 Calculated consequences of biogas production from 100 % pig slurry at farm biogas plant with a treatment capacity of 50 tonnes pr day.

Economic consequences				Consequence per year
Agriculture				
- reduced demand for synthetic fertilizer				7.2 tonnes
Biogas plant				
- electricity production for sale (total production)				760,003 kWh
- heat production – displaced gasoil				778,078 MJ = 21,692 litre
- investment costs				8.1 M DKK
- labour				365 hours
- electricity consumption				100,375 kWh
- water consumption				300 m^3
- chemicals				2,500 DKK
- service and maintenance				270,000 DKK
Emissions consequences	Total, tonnes	Agriculture, tonnes	Biogas, tonnes	Transport, tonnes
CO_2 emissions	- 353.751		- 353.751	0
N_2O emissions	- 0.557	- 0.563	0.006	0
CH_4 emissions	- 13.586	- 16.425	2.839	0
C content of soil	- 36.956	- 36.956		
particle emissions	0.004		0.004	0
NO_x emissions	1.094		1.094	0
SO_2 emissions	0.051		0.051	0
CO emissions	1.995		1.995	0
NMVOC emissi-	0.030		0.030	0
N-leaching	- 2.306	- 2.306		
Taxes and subsidies				
On-site CHP plant				
- reduced demand for gas oil – energy tax				53,744 DKK
- reduced demand for gas oil - CO_2 tax				9,111 DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.
Note: Amounts stated in DKK are stated in 2009 prices.

The consequences of biogas production taking place at a farm biogas plant with a daily input capacity of 50 tonnes with pig slurry constituting 100 % of the input are listed in Table 6.1.

Below the individual consequences are explained in more detail.

6.1.1 Economic consequences

Agriculture

The reduced demand for synthetic fertiliser brought about by the increased plant availability of N in treated as compared to untreated slurry is a linear function of the amount of treated slurry. Hence, the effect in scenario 1C is equal to 1/10 of the effect in scenario 1B, i.e. the demand for synthetic fertiliser is reduced by 7.2 tonnes per year.

Biogas plant

Biogas production per tonne of input is slightly different for the farm biogas compared to the joint biogas plants. The reason for this being that the production process is assumed to be mesophile process rather than thermophile, and that the time that the biomass is in the biogas reactor is longer (50 days compared to 20). The key factors used to calculate biogas production per tonne pig slurry for the farm biogas plant in scenario 1C are listed in Table 6.2.

A daily biomass input of 50 tonnes is equivalent to an annual biomass input of 18,250 tonnes, and with reference to Table 6.2 where the gas production per tonne of pig slurry is seen to be equal to 9.49 Nm^3 natural gas equivalents this implies that the gross annual production of the facility amounts to approximately 173,000 Nm^3 natural gas equivalents. Using that the lower heating value of natural gas is 39.6 MJ per Nm^3 this is equivalent to a gross annual production of 6,840,000 MJ.

Table 6.2 Calculated biogas production per tonne of pig slurry input for scenario 1C.

Dry matter (DM) content of pig slurry	4.5 %
Kg DM pr tonne pig slurry	45
VS/DM ratio [1]	0.8
Kg VS pr tonne pig slurry [1]	36
Nm^3 CH_4 pr kg VS (HRT=50 days) [1]	0.29
Nm^3 CH_4 pr tonne pig slurry	10.44
CH_4 content of biogas	60 %
Biogas production (Nm^3 pr tonne pig slurry)	17.4
Heating value CH_4 (lower; MJ pr Nm^3)	35.9
Heating value Natural gas (lower; MJ pr Nm^3)	39.9
Ratio: Natural gas/CH_4	1.1
Production in natural gas equivalents (Nm^3 pr tonne pig slurry)	9.49

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be decomposed.

In Table 6.3 it is specified how the produced biogas is used. In relation to the calculation of the process heat requirement for the farm biogas plants the energy requirement for heating biomass is 4.18 MJ per tonne per degree, the degree of heat recirculation is set to 55 % and it is assumed that there is a 20 % heat loss, i.e. identical assumptions to those made for the joint biogas plants. However, as the production process at the farm plants is assumed to be mesophilic rather than thermophilic the net heating requirement for the farm plants is 20 degrees instead of 40 degrees. Hence, the process heat requirement per tonne of input for the farm plants is 4.18 MJ pe tonne per degree 20 degrees $\cdot$ (1.2 – 0.55) = 54.34 MJ per tonne, which is significantly lower that the one applying to the joint plant scenarios. Consequently, the share of gross energy production used for process heat is significantly lower for scenario 1C compared to scenarios 1A and 1B, i.e. 14.5 % compared to 30 %. Total heat requirement for an annual biomass input of 18,250 tonnes is 991,750 MJ.

Table 6.3 Anticipated use of biogas production.

Use	Share of gross production (%)	Share in relevant energy equivalents
Gross energy production	100	172,728 Nm^3 Natural gas
Process heat [1]	14.5	991,705 MJ
Electricity for sale [1,2]	40	760,003 kWh
Excess heat production [1, 3]	38	2,593,593 MJ

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. All heat and electricity production is assumed to be produced at a on-site CHP facility.

2. Electricity for sale is equal to gross electricity production.

3. Of the excess heat production only 30 % are assumed to be used; the remaining 70 % are assumed to be lost.

In contrast to the joint biogas plant scenarios where the biogas production in excess of what is needed to cover the process heat requirement is sold to a local CHP facility the entire biogas production is assumed to be used on the on-plant CHP for the farm biogas plants. The entire amount of electricity (760,003 kWh) produced at the CHP is sold. For the heat share of energy production, the heat production in excess of what is required for process heat is equal to 2,593,593 MJ. Of this excess heat production it is assumed that 30 % is put to use on the farm (e.g. for heating of stables and housing), while the remaining 70 % is lost. Hence, a significant amount of the energy content of the biogas is effectively lost in the farm plant scenarios. The reason for this apparent waste of energy is that it is quite costly to transport heat from one place to another and consequently it is difficult to find economically feasible alternative uses for the heat. The 30 % of excess heat production replaces an amount of gasoil equal to 2,593,593 MJ $\cdot$ 0.30 : 35.87 MJ per litre = 21,692 litre.

In Table 6.4 the investment costs for scenario 1C are listed. The investment and operating costs for the biogas plant are based on information from Petersen (2010) and adjusted to fit this specific context. In terms of the CHP related investment costs it may be noted that the cost is based on the same cost per MJ as was used in the joint plant scenarios, i.e. 0.075 DKK per MJ. With a gross production of 172,728 Nm^3 Natural gas equivalents, which is equivalent to 6,840,027 MJ, estimated CHP investment costs becomes approximately 0.5 M DKK.

Table 6.4 Calculated investment costs for farm biogas plant with a capacity of 50 tonnes per day and 100 % pig slurry as input – M DKK, factor prices.

CHP	0.5
Biogas plant	7.2
Investment costs (A1)	7.7
Projecting/planning costs (5 % of A1)	0.4
Total investment costs	8.1

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

As it appears from Table 6.1 the time required for operating the plant is set to 365 hours. In addition to this 100,375 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 300 m^3 water. Also different chemicals are needed with factor price value equal to 2,500 DKK. Finally annual service and maintenance costs are set to 3.5 % of A1, i.e. 270,000 DKK.

6.1.2 Emission consequences

The agriculturally related emissions of N_2O and CH_4 emissions from agriculture, and the changes in the C content of the soil and in N-leaching, are directly proportional to the amount of input used for biogas production. Hence, the effects pertaining to scenario 1C are equal to 1/10 of the effects pertaining to scenario 1B.

Emissions consequences related to biogas production and use

Due to the fact that the biogas produced at the farm plant is assumed to be used differently than the biogas produced at joint plants, the emissions changes brought about by scenario 1C are different from those brought about by scenario 1A and 1B. Hence, estimates of the emissions changes induced by scenario 1C cannot be estimated by simple downscaling of the estimates from scenario 1B.

The nature of the emissions changes depend on how the biogas is used, and the more specific assumptions made regarding the origin of the energy production displaced by the produced biogas. In this context it is assumed that the electricity produced at the biogas plant displaces electricity produced with “average” production technology and the amount of electricity displaced is equal to gross electricity production from the on-plant CHP minus the electricity needed for running the plant. In terms of the produced heat, it is assumed that the 30 % of the excess heat production which is put to use displaced oil based heat production. The more specific energy related emissions changes pertaining to scenario 1C are listed in Table 6.5.

Table 6.5 Calculated emissions changes from the changes in energy production caused by the production of biogas from 100 % pig slurry at a farm biogas plant with a daily input capacity of 50 tonnes.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	Particles	NO_x	SO_2	CO	NMVOC
		EF (g pr MJ):	0.00	0.00	0.43	0.00	0.20	0.02	0.31	0.01
Biogas based CHP production	Total production (6,840,000 MJ)	Change (tonne):	0	0.011	2.969	0.018	1.382	0.131	2.120	0.068
Reduced production of electricity with average production technology	Net electricity sale from biogas plant (2,374,661 MJ)	EF (g pr MJ):	124.72	0.00	0.05	0.00	0.10	0.03	0.04	0.01
		Change (tonne):	-296.173	-0.004	-0.129	-0.01	-0.247	-0.063	-0.092	-0.026
Reduced use of oil for heat production[1]	Displaced oil-based heat production (778,078 MJ)	EF (g pr MJ):	74.00	0.00	0.00	0.01	0.05	0.02	0.04	0.02
		Change (tonne):	-57.578	-0.001	-0.001	-0.004	-0.041	-0.018	-0.034	-0.012
Total net change in emissions			-353.751	0.006	2.839	0.004	1.094	0.051	1.995	0.030

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity), Nielsen et al. (2010) (biogas) and Danmarks Miljøundersøgelser (2011) (oil).

Note 1: It is assumed that 30 % of the excess heat production is used.

From Table 6.5 it is seen that overall the production of biogas and the associated changes in fuel use in energy production entail net increases in all emissions but CO_2.

6.1.3 Taxes and subsidies

In relation to taxes and subsidies, there is an important difference between the joint plant scenarios and scenario 1C. Hence, the 20 % construction subsidy does not apply to conventional farm biogas plants.

As 30 % of the excess heat production at the on-site CHP displaces gasoil consumption the State will lose tax income from gasoil tax of 2.479 DKK per litre gasoil and CO_2 tax of 0.42 DKK per litre gasoil. The amount of gasoil displaced is equal to 21,692 litre and therefore, lost tax income can be calculated as 53,774 DKK and 9,111 DKK, respectively.

In total the State annually loses a tax income of 62,885 DKK. This amount is important for the welfare economic calculations, because it represents a so-called tax distortion loss. Of course, the subsidies and tax exemptions are also important for the financial calculations which inter alia show how the economic situation of biogas plant and local CHP plant is affected by the biogas production and use.

6.2 Welfare economic analysis

In Table 6.6 the welfare economic consequences associated with biogas production according to scenario 1C, their accounting prices, and their resulting welfare economic value are listed. The approaches used in the calculations are similar to those used in scenario 1A; hence, for specification of the calculation principles, reference is made to Chapter 4. Here we solely present the results.

It is seen from the table the total annual welfare economic value of biogas production from 100 % pig slurry at a biogas plant with a treatment capacity of 50 tonnes per day is equal to - 0.43 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss 0.49 M DKK - 0.07 M DKK and 0.01 M DKK are due to economic consequences, emission consequences and taxes and subsidies respectively. Especially the value of electricity sold, investment costs and service and maintenance costs are important for the total result.

Subsidies and loss of taxes which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 0.01 M DKK to society. This is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases which are the occasion of so-called dead weight losses. The assumption of necessary tax increases to finance expenditures and tax losses is requested by the Danish Ministry of Finance in connection with welfare economic analyses, but the assumption can of be discussed – cf. Møller & Jensen (2004). Other financing possibilities which do not lead to dead weight losses are possible. If the financing problem is ignored production and use of biogas still lead to a welfare economic loss 0.42 M DKK.

Table 6.6 Calculated welfare economic value of biogas production from 100 % pig slurry at a farm biogas plant with a treatment capacity of 50 tonnes pr day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			-0.49
Agriculture			
- reduced demand for synthetic	7.2 tonnes	7,500 DKK pr tonne · 1,17	0.06
Biogas plant			
- electricity production for sale	760,003 kWh	0.46 DKK pr kWh · 1.17	0.41
- heat production – displaced gasoil	778,078 MJ = 21,692 litre	110 DKK pr GJ · 1.17	0.10
- investment costs	0.5 M DKK	0.5 M DKK · 1.17	- 0.59
- labour	365 hours	200 DKK · 1.17	- 0.09
- electricity consumption	100,375 kWh	0.46 DKK pr kWh · 1.17	- 0.05
- water consumption	300 m^3	25 DKK pr m^3 · 1,17	- 0.01
- chemicals	2.500 DKK	2.500 DKK · 1.17	- 0.00
- service and maintenance	270,000 DKK	270,000 DKK · 1.17	- 0.32
Emission consequences			0.07
- CO_2 emissions [1]	- 353.751 + 296.173	105 DKK pr tonne · 1.17	0.01
- N_2O emissions	- 0.557tonnes	105 DKK pr tonne · 310 · 1.17	0.02
- CH_4 emissions	- 13.586 tonnes	105 DKK pr tonne · 21 · 1.17	0.03
- C content of soil	- 36.956 tonnes	105 DKK pr tonne · 3,67· 1,17	- 0.02
- particle emissions	0.004 tonnes		
- NO_x emissions	1.094 tonnes	55,000 DKK pr tonne	-0.06
- SO_2 emissions	0.051 tonnes	85,000 DKK pr tonne	-0.00
- CO emissions	1.995 tonnes		
- NMVOC emissions	0.030 tonnes		
- N-leaching	- 2.306 tonnes	40,000 DKK pr tonne	0.09
Public net income	- 62,885 DKK	-62,885 DKK · 0,2	- 0.01
Total			- 0.43

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK pr kWh · 1.17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 353.751 tonnes deducted reduced CO_2 emissions from alternative electricity production 296.173 tonnes.

The total annual reduction in greenhouse gas emissions brought about by the scenario is: (353.751 + 0.557 *310 + 13.586 * 21 - 36.956 * 3.67) tonne = 676 tonnes CO_2 equivalents and the value of this reduction is equal to 0.083 M DKK. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 0.51 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case 754 DKK per tonne CO_2.

It is also seen from the table that the costs to society of reduced C content of soil and increased NO_x emissions (due to higher NO_x emission coefficient for biogas than for natural gas) are higher than the value of reduced climate gas emissions. It is only because of the value of reduced N-leaching that biogas production at a 50 tonnes production plant based on 100 % pig slurry does seem to be favourable from an environmental point of view. But overall biogas production at a plant like this does not seem to be favourable to society.

Below, the individual entries of the welfare economic account are explained.

6.2.1 Value of economic consequences

Generally accounting prices of economic consequences are determined as for scenario 1A – cf. Section 4.2.1. Compared to this scenario it is only the accounting price of gasoil, which has to be determined. The expected price of 110 DKK per GJ is stated in Energistyrelsen (2010a).

6.2.2 Value of emission consequences

With regard to determination of accounting prices for emission consequences refer to Section 4.2.2.

6.2.3 Public net income – tax distortion loss

In Section 6.1.3 it was calculated that the public sector will loose annual tax incomes that equal 62,885 DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 0.01 M DKK.

6.3 Financial analysis

In Table 6.7 the results of the financial analysis pertaining to scenario 1C are presented. As was the case for the welfare economic analysis, reference is made to Section 4.3 for a detailed description of the principles applied in the calculations. Only the price of gasoil and the annual investment costs need to be explained.

Table 6.7 Calculated financial consequences of biogas production from 100 % pig slurry at a farm biogas plant with a treatment capacity of 50 tonnes pr day – M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			0.05 M DKK
- reduced demand for synthetic fertilizer	7.2 tonnes	7,500 DKK pr tonne	0.05 M DKK
Biogas plant			- 0.28 M DKK
- electricity production for sale	760,003 kWh	0.772 DKK pr kWh	0.59 M DKK
- heat production – displaced gasoil	778,078 MJ = 21,692	6.845 DKK pr litre	0.15 M DKK
- investment costs	0.598 M DKK	-	- 0.60 M DKK
- labour	365 hours	200 DKK pr hour	- 0.07 M DKK
- electricity consumption	100,375 kWh	0.65 DKK pr kWh	- 0.07 M DKK
- water consumption	300 m^3	25 DKK pr m^3	- 0.01 M DKK
- chemicals	2.500 DKK	2.500 DKK	- 0.00 M DKK
- service and maintenance	270,000 DKK	270,000 DKK	- 0.27 M DKK
The state			- 0.06 M DKK
- reduced demand for gas oil – energy tax	53,744 DKK		- 0.05 M DKK
- reduced demand for gas oil - CO_2 tax	9,111 DKK		- 0.01 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

The price of gasoil equal to 6.845 DKK per litre is determined on the basis of a consumer price of 110 DKK per GJ, which is equal to 110 DKK per GJ · 0.03587 GJ per litre = 3.9457 DKK per litre. To this is added energy tax of 2.479 DKK per litre and CO_2 tax of 0.42 DKK per litre; in total this adds up to the stated price of 6.845 DKK per litre.

The annual investment costs of 0.598 M DKK are determined by annualizing the investment costs of 8.1 M DKK over a 25 years life time of the plant and an interest rate of 6 %.

It is seen from Table 6.7 that the agricultural sector is an economic winner while the biogas plant and the state both are losers. However, as the biogas plant is owned by farmers overall the agricultural sector will also be a loser.

7 Scenario 2A: Biogas production from 75 % conventional pig slurry and 25 % maize at 800 tonnes pr day plant

In scenario 2A biogas production takes place at joint biogas plant with a treatment capacity of 800 tonnes per day. Pig slurry from slaughter pigs constitutes 75 % of the input and maize constitutes the remaining 25 % of input. In terms of maize it is assumed that the growing of maize for biogas production displaces the production of winter wheat for sale. Moreover, it is assumed that the growing of crops takes place on clay soils - JB 5-6 of the Danish soil classification system.

The annual biomass input requirement of the biogas plant is 292,000 tonnes, where pig slurry accounts for 219.000 tonnes and maize for 73,000 tonnes. In terms of the slurry input requirement it is equivalent to the annual slurry production from 317,700 slaughter pigs (8,825 LU). In relation to determining the amount of agricultural land needed for producing the required amount of maize, it is assumed that the average maize production per hectare is 42.9 tonnes. This amount is based on the assumption of a production of 11,000 FE per ha and 1.17 kg DM per FE and a 30 % DM content of maize – cf. Videncentret for landbrug (2010a). With an average maize production per hectare of 42.9 tonnes satisfying the input requirement requires that 1,702 hectares are converted from winter wheat to maize. This change in land use is associated with changes in the use of resources used in agricultural production, e.g. changes in the use of labour and machinery.

As in scenarios 1A it is assumed that the biomass for biogas production – both slurry and plant material – is returned to the supplying farmer where the treated biomass is used as fertiliser. Also, similar to scenario 1A it is assumed that the average distance between the farms and the biogas plant is 10 km. The total transport requirement, however, is larger for scenario 2A than it is for scenario 1A. Hence, where it in the 100 % slurry scenarios is reasonable to assume that it is possible to drive with return loads all the time, this assumption is not applicable to scenarios involving plant material. More specifically, the problem arise due to the fact that while untreated slurry and treated biomass (slurry + plant material) is transported in tank trucks the raw plant material part of the input has to be transported on lorries. Thus, transport of untreated and treated plant material requires two different modes of transport, implying that the lorries and tank trucks used to transport the plant share of the biomass drive empty half of the time (to and from the biogas plant, respectively). The capacity of lorries as well as tank trucks is assumed to be 30 tonnes.

In terms of the use of the biogas production scenario 2A is similar to scenario 1A implying that part of the biogas is used for CHP production at an onsite CHP installation dimensioned according to the process heat requirement, whereas the rest is sold to a local CHP located 3 km's from the biogas plant where it is assumed to substitute natural gas in the production of heat and electricity.

The use of digested biomass as fertilizer in stead of untreated slurry and synthetic fertilizer is associated with a reduction in the need for application of synthetic fertiliser and a subsequent reduction in N-leaching. Moreover, it also gives rise to changes in the emissions of CH_4 and N_2O just as it has implications in relation to the C-content of the soil. Hence, the agriculturally related effects of scenario 2A are similar to those of scenario 1A, but the magnitude of the effects is different due to differences in the properties of the input used for biogas production.

As in scenario 1A, the increased transport requirement associated with the transportation of biomass to and from the biogas plant also gives rise to emissions changes. In addition to this, however, emissions changes also arise due to the changes in land use practices induced by the displacement of wheat production by maize production; hence, the resource requirements in terms of use of machinery differs between the two types of crops. Finally, the substitutions induced in the energy production sector by the production of biogas, also give rise to emissions changes.

7.1 Consequence description

In Table 7.1 the consequences of biogas production from 75 % pig slurry and 25 % maize silage at a biogas plant with a treatment capacity of 800 tonnes per day are summarized. The table is divided in three parts covering economic consequences, emissions and taxes and subsidies respectively. Economic consequences include the consequences for production and use of material input of re-allocating society’s scarce resources. Emissions include the consequences for the discharge of different matters into the environment of the resource re-allocation. Taxes and subsidies concern the consequences for the State’s net income of subsidizing biogas production through direct investment support and exemption from tax payments when energy production is based on biogas.

Below the individual consequences are explained in more detail.

Table 7.1 Calculated consequences of biogas production from 75 % pig slurry and 25 % maize silage at biogas plant with a treatment capacity of 800 tonnes pr day.

Economic consequences	Consequence per year
Agriculture – production	
- wheat production	- 15,145 tonnes
- maize production	73,000 tonnes
Agriculture – resource use	
- wheat seed	- 289 tonnes
- maize seed	3,403 pk
- labour	795 hours
- N fertilizer (synthetic and organic)	- 32 tonnes
- P fertilizer	20 tonnes
- K fertilizer	99 tonnes
- plant protection	0.017 M DKK
- fuel consumption (diesel)	10,269 litre
- machine services[1]	0.151 M DKK
- maintenance of machines[1]	0.088 M DKK
- reduced demand for synthetic N fertilizer	- 278 tonnes
Transport	
- slurry and maize to biogas plant and residual	365,000 km
- export of wheat	- 37,861 km
Biogas plant	
- biogas production for sale	6,512,573 Nm^3
- electricity production for sale	5,876,770 kWh
- investment costs[1]	87.7 M DKK (total amount)
- labour	2 persons' work
- electricity consumption	1,606,000 kWh
- water consumption	1,000 m^3
- chemicals[1]	25,000 DKK
- service and maintenance[1]	2,852,000 DKK

Emission consequences	Total, tonne	Agriculture [2] tonne	Biogas, tonne	Transport – biomass for biogas, tonne	Transport – displaced production, tonne
- CO_2	-16,135.630	27.339	-16,427.330	294.958	-30.596
- N_2O	4.244	3.912	0.322	0.011	-0.001
- CH_4	-140.786	-150.857	10.058	0.015	-0.002
- C content of soil	-461.215	-461.215			
- particles	0.612	0.019	0.562	0.035	-0.004
- NO_x	28.681	0.241	26.471	2.197	-0.228
- SO_2	5.515	0.001	5.512	0.002	0
- CO	81.282	0.136	80.829	0.354	-0.037
- NMVOC	-20.704	0.025	-20.778	0.055	-0.006
- N-leaching	-11.248	-11.248			

Taxes and subsidies	
Biogas plant	
- construction subsidy (20 %)	17.5 M DKK (total amount)
CHP plant	
- biogas based power production (subsidy)	- 11.777 M DKK
- CO_2 tax exemption	- 2.286 M DKK
- exemption from tax on natural gas for heat production	- 4.832 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter. Notes: 1. Amounts stated in DKK are stated in 2009 prices. 2. The agriculturally related changes in N_2O and CH_4 emissions includes the changes associated with changed use of diesel in agricultural machinery and the changes brought about by using slurry and plant material for biogas production prior to field application.

7.1.1 Economic consequences

Agriculture

The economic consequences for the agricultural sector are shown in Table 7.2. and are first of all connected with the substitution of 15,145 tonnes wheat production with 73,000 tonnes maize production. This means that resource use will change. The changes in resource use are based on Videncentret for landbrug (2010a), although some adjustments are made. The adjustments will be described in the following. In Videncentret for landbrug (2010a) machine and labour costs are not separated. For the present analysis it is preferable that costs related to labour, fuel use and machines are assessed separately. In order to obtain separate estimates of these different costs, the approach used in Møller and Slentø (2010) is adopted in the present study. Accordingly, labour costs are assumed to account for 27 % of total machine and labour costs, maintenance of machines are assumed to account for 20 %, fuel for 10 % while the remaining 43 % can be ascribed to depreciation of machine investments. Subsequently the costs ascribable to labour and fuel are translated into changes in absolute changes in hours and litres using a price of labour of 150 DKK per hour and a diesel cost of 4.3 DKK per litre (i.e. the values used in Videncentret for landbrug (2010a)). In addition to this, the 43 % ascribable to depreciation of machine investments are adjusted to reflect the social rate of discount relevant for welfare economic analysis rather than the market rate of interest used in Videncentret for landbrug (2010a).

The more specific changes in resource use are specified in Table 7.2. Here it is seen that in addition to the effects directly related with the changed land used the biogas treatment of slurry also results in a reduction in the need for synthetic fertilizer as was the case in the 100 % pig slurry scenarios. The effect of biogas treatment on the plant availability of N only applies to the N in slurry. The reduction in synthetic fertiliser application is equivalent to 10 % of the total N content of the slurry – cf. Section 4.1.1. 219,000 tonnes slurry is used, and as the N content of pig slurry is equal to 3.93 kg N per tonne slurry this translates into an annual reduction in fertiliser application of 86 tonnes.

Table 7.2 Calculated economic consequences of replacing wheat production with maize production on 1,702 ha land.

	Wheat production	Maize production	Net change
Agriculture – production			
- wheat production	- 15,145 tonnes		- 15,145 tonnes
- maize production		73,000 tonnes	73,000 tonnes
Agriculture – resource use			
- wheat seed	- 289 tonnes		- 289 tonnes
- maize seed		3,403 pk	3,403 pk
- labour	- 10,774 hours	11,569 hours	795 hours
- N fertilizer (synthetic and organic)	276	243	- 32 tonnes
- P fertilizer	49	70	20 tonnes
- K fertilizer	163	262	99 tonnes
- plant protection	- 1.064 M DKK	1.081 M DKK	0.017 M DKK
- fuel consumption (diesel)	- 139.5 thousand litre	149.8 thousand litre	10.3 thousand litre
- machine services	- 2.053 M DKK	2.204 M DKK	0.151 M DKK
- maintenance of machines	- 1.198 M DKK	1.286 M DKK	0.088 M DKK
Agriculture – treated slurry and maize			
- reduced demand for synthetic N fertilizer			- 278 tonnes

Source: Own calculations based on information about production and resource use per ha in Videncentret for landbrug (2010a) and data from the BIOMAN partners and other sources mentioned in the chapter.

In addition to this reduction caused by the improved plant availability of N in the slurry part of the input a reduction in the need for synthetic fertiliser also arises because synthetic fertiliser can be replaced by treated maize. Here it is assumed that the application of synthetic fertiliser N can be reduced by 70 kg per hkg N in the treated maize. The N content of maize is assumed to be 12,5 kg per tonne DM. With a DM content of 30 % this translates into a N content of maize of 3.75 kg N per tonne. For scenario 2A where the total annual maize input is 73.000 tonne the total N-content is 2.737,5 hkg, the resulting reduction in the need for synthetic N fertiliser application is 192 tonne. In total the annual need for synthetic N fertilizer is reduced with 278 tonne because of the fertilizer effect of treated slurry and maize

Transport

As mentioned in the beginning of the chapter, the transport requirement associated with transporting biomass between the supplying farms and the biogas plant are higher for the scenarios using plant material as input than it is for scenarios solely relying on slurry as input. The reason being that transport inefficiencies are introduced due to the fact that while raw plant material has to be transported by lorries treated plant material has to be transported by tank trucks. Consequently, the trucks and lorries used to transport the plant material part of the input cannot drive with return loads - i.e. they drive empty half of the time.

The key factors used to calculate the transport requirement associated with transport to and from the biogas plant in scenario 2A are listed Table 7.3. It can be seen that the transport requirement is 219,000 tonnes: 30 tonnes · 30 km = 219,000 km for slurry and treated slurry, 73,000 tonnes: 30 tonnes · 30 km = 73,000 km for treated maize and 73,000 tonnes: 30 tonnes · 30 km = 73,000 km for untreated maize. Total transport requirement is 365,000 km.

Table 7.3 Calculations of annual biomass related transport requirement for scenario 2A.

Slurry to biogas plant (tonnes per year)	219.000
Maize to biogas plant (tonnes per year)	73.000
Treated biomass from biogas plant (tonnes per year)	292.000
Distance between farm and biogas plant (km; one way/return)	15/30
Capacity of tank trucks and lorries (tonnes)	30
Number of return trips tank trucks (slurry and treated maize)	7.300 (slurry) + 2.433 (treated maize)
Number of return trips lorries (maize to biogas plant)	2.433
Total number of km	365.000

Apart from the increased need for transport associated with the transport of biomass to and from the biogas plant a change in the need for transport also arise in connection with the changes in land use induced by the displacement of wheat production by the production of maize as input to biogas production. Transport requirement might either decrease or increase depending on how the wheat production has been used until now. If the wheat has been exported transport the requirement will decrease as it is not necessary to transport the 15,145 tonnes wheat to the border any longer. If the wheat has been used as fodder at the farms it is now necessary to replace it with imported wheat and this will increase the need of transport. As Denmark is a net exporter of wheat it is assumed in this analysis that the lost wheat production has been exported and therefore, the need of transport decreases. Assuming the average distance to the border to be 75 km and assuming that the 15,145 tonnes wheat was transported to the border on 30 tonnes lorries the associated decrease in the need for transport is 75 km · (15,145 tonnes : 30 tonnes) = 37,861 km.

Biogas plant

The key factors used to calculate biogas production per tonne of input are listed in the Table 7.4 below. For pig slurry, biogas production per tonne of slurry is identical to the production calculated in relation to scenario 1A. For maize the DM content is assumed to be 30 %, and this – combined with the higher VS/DM ratio and higher gas production per kg of VS – result in an almost eight times higher gas production per tonne of maize than per tonne of pig slurry. With an input consisting of 75 % pig slurry and 25 % maize the average biogas production per tonne of input for scenario 2A is 26.88 Nm^3 natural gas equivalents per tonne input. This is a much higher amount than in scenario 1A where only 9.14 Nm^3 natural gas equivalents per tonne pig slurry was produced.

Table 7.4 Calculated biogas production per tonne of pig slurry and maize input.

	Pig slurry (75 % of input)	Maize (25 % of input)
Dry matter (DM) content	4.5 %	30 %
Kg DM pr tonnes	45	300
VS/DM ratio [1]	0.8	0.95
Kg VS pr tonnes [1]	36	285
Nm^3 CH_4 pr kg VS (HRT=50 days) [1]	0.28	0.31
Nm^3 CH_4 pr tonnes	10.08	88.35
CH_4 content of biogas	60 %	60 %
Biogas production (Nm^3 pr tonnes)	16.8	147.3
Heating value CH_4 (lower; MJ pr Nm^3)	35.9	35.9
Heating value Natural gas (lower; MJ pr Nm^3)	39.9	39.9
Ratio: Natural gas/CH_4	1.1	1.1
Production in natural gas equivalents (Nm^3 pr tonnes)	9.16	80.32
Production in natural gas equivalents Nm^3 pr tonnes		26.88

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be decomposed.

The annual biomass input is 292,000 tonnes and with a biogas production of 26.88 Nm^3 natural gas equivalents per tonne biomass input this implies that the gross annual production of the facility amounts to 7,848,202 Nm^3 natural gas equivalents. Using that the lower heating value of natural gas is 39,6 MJ pr Nm^3 this is equivalent to a gross annual production of 310,788,813 MJ.

Table 7.5 Calculation of biogas production.

	Share of gross production (%)	Share in relevant energy equivalents
Gross energy production	100.0	7,848,202 Nm^3 Natural gas eq.
Process heat [1]	10.2	31,734,560 MJ
Electricity for sale [1]	6.8	5.876.770 kWh
Biogas for sale	83.0	6.512.573 Nm^3 natural gas eq.

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

1. Process heat and electricity for sale is assumed to be produced at an on-site CHP facility.

In Table 7.5 it is specified how the produced biogas is used. It can be seen form the table that of a total production of 8,848,202 Nm^3 natural gas equivalents biogas about 83 % of it 6,512,573 Nm^3 (257,897,880 MJ) can be sold to a local CHP plant. The remaining 17 % is used for process heat for biogas production. The heat is as in scenario 1A assumed to be supplied from an on-plant CHP facility which uses biogas as fuel.

This on-plant CHP facility is, as previously mentioned, dimensioned according to the process heat requirement related to the heating of the input material. As explained in Section 4.1.1 the amount of energy necessary to cover the process heat requirement depends on 1) the amount of biomass to be heated, 2) the net heating requirement (difference between the temperature of the input biomass and the temperature in the reactor), 3) the degree of heat recirculation and 4) the degree of heat loss. The energy requirement for heating biomass input is the same 4.18 MJ pr tonne pr degree whether input is 100 % pig slurry or 75 % pig slurry and 25 % maize and therefore process heat requirement can be calculated as 31,734,560 MJ – see Section 4.1.1 for details. The production of heat at the on-site CHP facility is associated with a joint production of electricity and the amount of electricity produced is 5,876,770 kWh as in scenario 1A.

The investment costs for the scenario are presented in Table 7.6, where it appears that operating the biogas plant is assumed to include employment of two skilled workmen. In addition to this 1,898,000 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 1,000 m^3 water. Also different chemicals are needed with factor price value equal to 25,000 DKK. Finally annual service and maintenance costs of the biogas plant are set to 3.5 % of A1, which is equal to 2,852,000 DKK. The investment ans operating cost calculations are based on Petersen (2010), but adjusted to fit this specific context.

Table 7.6 Calculation of investment costs for biogas plant with a capacity of 800 tonnes per day and 75 % pig slurry and 25 % maize as input – M DKK, factor prices.

Buildings, roads, etc.	14.8
Storage facilities for maize	12.5
Pre-treatment of maize	2.0
Reactors, pipes, etc.	17.8
Gas scrubbers	6.0
CRS (Control, Regulation , Supervision system)	15.2
Pumps etc.	6.3
CHP	3.9
Building site	3.0
Investment costs (A1)	81.5
Gas pipeline	2.1
Projecting/planning costs (5 % of A1)	4.1
Total investment costs	87.7

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

7.1.2 Emission consequences

The total emission consequences stated in Table 7.1 are the result of the resource re-allocations described in Section 7.1.1 and like these they can be related to agriculture, transport and biogas production and use respectively. The consequences of these three activities are summarized in Table 7.7.

Table 7.7 Emission consequences of biogas production from 75 % pig slurry and 25 % maize silage at biogas plant with a treatment capacity of 800 tonnes per day - tonne.

Activities	CO_2	N_2O	CH_4	C content of soil	Particles	NO_x	SO_2	CO	NMVOC	N-leaching
Agriculture – biomass		3.911	-150.857	-461.215						-11.248
Agriculture - energy	27.339	0.001	0		0.019	0.241	0.001	0.136	0.025	
Transport – biomass	294.958	0.011	0.015		0.035	2.197	0.002	0.354	0.055	
Transport – wheat	-30.596	-0.001	-0.002		-0.004	-0.228	0	-0.037	-0.006	
Biogas production and use	-16,427.33	0.322	10.058		0.562	26.471	5.512	80.829	-20.778	
Total	-16,135.630	4.244	-140.786	-461.215	0.612	28.681	5.515	81.282	-20.704	-11.248

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Below the different emission changes are explained in more detail.

Emission consequences related to agriculture

Emission consequences related to agriculture are first of all caused by the change in use of biomass, which leads to changes in N_2O and CH_4 emissions, C-content of the soil and N-leaching. In relation to NH_3 emissions it is assumed that the increases caused by the higher pH value of treated slurry compared to untreated slurry cancel out with the reductions caused by the increased viscosity of treated slurry compared to untreated slurry. Finally the change in land use where areas with wheat are replaced by maize causes some minor changes in energy consumption related to use of machines. These energy consumption changes have consequences for air emissions.

In terms of N_2O several factors contribute to emission changes. The calculation of changes in N_2O emissions is based on the emissions coefficients specified in Appendix I. The fact that plant material is now used as an input imply that the changes in N_2O emissions induced by the production of biogas are more complicated to assess for scenario 2A than they were for scenario 1A where slurry constituted the sole input to biogas production.

For untreated pig slurry applied to the field in May the N_2O-N emissions coefficient is set to 2.25 % of the total N-content of the slurry. For the treated biomass, that is slurry as well as maize applied to the field in May, the N_2O-N emissions coefficient is also set to 2.2 5% of the total N-content of the biomass. As the N-content of the slurry is unaffected by the production of biogas there are no change in the N_2O emissions originating from the slurry part of the input between the reference situation and the biogas scenario.

However, for the maize part of the input N_2O-N emissions increase from zero to 2.25 % of the N-content of the maize. With a total annual maize input of 73,000 tonnes and the N-content of maize set to 3.75 kg per tonnes the total amount of N in the treated maize is 273.756 tonnes and the resulting increase in N_20-N emissions is 6.159 tonnes. Using the conversion factor between N_2O-N and N_2O of 44/28 this translates into an increase in N_2O emissions of 9.679 tonnes.

As was the case in the 100 % pig slurry scenarios N_2O emissions in scenario 2A are also affected by the changed demand for synthetic fertiliser. As N_2O-

N emissions from synthetic fertiliser are set to 1 % of the N-content of the fertiliser the fertiliser related reduction in N_2O-N emissions for scenario 2A is equivalent to 1 % of the 278 + 32 = 310 ton reduction specified in Section 7.1.1. That is, N_2O-N emissions are reduced by 3.100 tonnes, which is equivalent to a reduction in N_2O emissions of 4.872 tonnes.

Finally, the level of N_2O emissions are also affected by differences in the N-content of the crop residue left on the fields in reference situation (wheat production) and the biogas scenario (maize production). More specifically, it is estimated that the total annual N_2O emissions will be reduced by 0.896 tonne due to changes in the N-content of crop residues.

In total, N_2O emissions related to agriculture for scenario 2A increase by 3.911 tonnes compared to the reference situation.

For pig slurry biogas treatment reduces CH_4 emissions by 0.9 kg per tonne of slurry (Møller & Olesen, 2011). In the present scenario, where the annual input of slurry is 219,000 tonnes, the resulting reduction in CH_4 emissions is 197.1 tonnes.

Where the use of slurry for biogas production gives rise to a reduction in CH_4 emissions the opposite is the case when using plant material for biogas production. Hence, for plant material CH_4 emissions are 0 in the reference situation while it in the biogas scenario is set to 1 % of the gross CH_4 production originating from the plant material (Møller, 2011). The total annual maize input of the scenario is 73,000 tonnes and using that the CH_4 production per tonne of maize is 88.35 m^3 the gross maize based CH_4 production amounts to 6,449,550 Nm^3. Consequently, the increase in CH_4 emissions is 64,495.5 Nm^3, which – using that the density of CH_4 is 0.717 kg per Nm^3 – is equivalent to an increase of 46.243 tonnes.

With reference to the above, the reduction in CH_4 emissions brought about by scenario 2A is greater than the increase. Hence, in total the scenario entails a reduction in CH_4 emissions of 150.857 tonnes per year.

As previously mentioned, the biogas treatment of slurry leads to a reduction in soil C. The more specific slurry related reduction in soil C associated with scenario 2A is calculated following the approach described in Section 4.1.2 and is found to be 443.475 tonnes per year.

Growing maize in stead of wheat (straw incorporation was assumed) is associated with a decrease in the C-content of the soil even though a minor part of the maize organic matter is assumed undigested and to be returned to the soil with the biogas slurry. More specifically, the reduction in soil C induced by the transition to maize production in stead of wheat production is estimated to be 0.010425 tonne per ha. The calculated change in soil C is based on Coleman & Jenkinson (1996), Sørensen (1987) and Olesen (2011) For scenario 2A where 1,702 hectares are used for the production of maize for biogas the resulting decrease in soil C is 17.740 tonnes.

In total, the decrease in the C-content of the soil is 461.215 tonnes per year.

As was the case in the 100 % pig slurry scenarios the level of N-leaching is also affected by biogas production in scenario 2A. However, here two effects working in opposite directions are in play.

As described in Section 7.1.1 the biogas treatment of slurry implies that the application of synthetic fertiliser can be reduced and subsequently the level of N-leaching is reduced by an estimated 4,5 kg N per ha. Based on a slurry application rate of 35.6 tonnes per ha the 219,000 tonnes of slurry used for biogas production is equivalent to the amount of slurry applied on 6,149.7 ha. Assuming that the level of N-leaching is reduced on all these hectares the resulting reduction in N-leaching is 27.670 tonnes N.

In relation to the maize part of the treated biomass, it is assumed that it - when applied to the field as fertiliser – displaces synthetic fertiliser and this leads to an increase in the level of N-leaching. More specifically, the utilization ratio of N in maize slurry is assumed equal to that of cattle slurry and N-leaching from cattle slurry is estimated to be approximately 6 kg N per hkg total-N applied greater than N-leaching from synthetic fertiliser. The N content of maize is 12.5 kg per tonnes DM and as maize has a DM content of 30 % the total amount of N in the 73,000 tonnes of maize treated in the biogas plant is 2,737.5 hkg. The resulting increase in N-leaching is 0.006 tonnes N PER hkg 2,737.5 hkg = 16.425 tonnes N.

Comparing the reduction in N-leaching with the increase it is seen that in total the level of N-leaching is reduced by biogas production. More specifically, the annual reduction in N-leaching is 11.249 tonnes N. Finally, it may be noted that it in relation to N-leaching is assumed that there are no differences in the amount of N-leaching from the growing of wheat and the growing of maize. Hence, it is assumed that no changes in N-leaching are induced by the changes in crop rotation caused by the displacement of wheat production with maize production.

However, the replacement of wheat production with maize gives rise to some minor emission consequences related to use of machines. These consequences are stated in Table 7.8.

Table 7.8 Calculation of emission consequences of increased diesel use associated with producing maize instead of wheat - tonnes.

	CO_2	N_2O	CH_4	Particles	NO_x	SO_2	CO	NMVOC
Emission factors								
Diesel g pr. MJ	74.000	0.003	0.001	0.051	0.654	0.002	0.368	0.066
Emissions								
Machines								
+ 369,440 MJ diesel (tonnes)	27.339.	0.001	0.000	0.019	0.241	0.001	0.136	0.025

Source: Changes in emissions are calculated based on emissions coefficients from Winther (2011).

Growing maize needs more use of machines than wheat growing. As stated in Section 7.1.1 this means an increase in annual consumption of diesel of 10,300 litre. With a specific gravity of 0.84 kg per litre this is equal to 8,652 kg diesel. Diesel has a calorific value of 42.7 MJ per kg and therefore, the total change in energy consumption related to machine use can be calculated as 8,652 kg · 40.65 MJ per kg = 369,440 MJ as stated in Table 7.8. Emission factors related to diesel are stated in the table as well and on the basis of these and the calculated change in energy consumption the emission changes can be calculated.

Emissions consequences related to transport

The increase in emissions from transporting biomass between farms and biogas plant – total 365,000 km – and the emission decrease caused by reduced export of wheat – total 37,861 km – are calculated on the basis of the same assumptions about emission coefficients, calorific value of diesel and diesel consumption per km as in scenario 1A – cf. Section 4.1.2.

Emissions consequences related to biogas production and use

The emission changes related to biogas production and use are calculated on the basis of the same method and assumptions about emission coefficients as for scenario 1A in Section 4.1.2. The results for the 75 % pig slurry and 25 % maize scenario are summarized in Table 7.9.

Table 7.9 Calculation of emissions changes from the changes in energy production caused by the production of biogas from 75 % pig slurry and 25 % maize at a joint biogas plant with a daily input capacity of 800 tonnes.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	Particles	NO_x	SO_2	CO	NMVOC
Biogas based CHP-production	Total production	EF (g per MJ)	0.00	0.00	0.43	0.00	0.20	0.02	0.31	0.01
	(310,788,813 MJ)	Change (tonne)	0	0.497	134.882	0.817	62.779	5.967	96.345	3.108
Reduced production of electricity with coal as fuel	Net electricity sale from biogas plant	EF (g per MJ)	124.72	0.00	0.05	0.00	0.10	0.03	0.04	0.01
	(14,323,573 MJ)	Change (tonne)	-1,786.468	-0.026	-0.776	-0.060	-1.492	-0.378	-0.557	-0.159
Reduced use of natural gas at local CHP	Biogas sold to local CHP	EF (g per MJ)	56.77	0.0006	0.48	0.00	0.14	0.00	0.06	0.09
	(257,897,880 MJ)	Change (tonne)	-14,640.863	-0.150	-124.049	-0.196	-34.816	-0.077	-14.958	-23.727
Total net change in emissions (tonne):			-16,427.331	0.322	10.058	0.562	26.471	5.512	80.829	-20.778

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity) and Nielsen et al. (2010) (biogas and natural gas).

It is seen from Table 7.9 that like in 100 % pig scenario CO_2 and NMVOC emissions will decrease while all other emissions increase.

7.1.3 Taxes and subsidies

Consequences for taxes and subsidies are calculated as in scenario 1A – cf. Section 4.1.3.

First of all biogas production is subsidized directly with a subsidy of 20 pct. of the total investment cost of 87.7 M DKK This means a governmental expenditure of 17.5 M DKK.

Secondly use of biogas at the local CHP plant is also subsidized in different ways which depends on the amount of power produced and amount of biogas replaced – see Section 3.1. The amount of biogas produced which replaces natural gas at the local CHP is equal to 6,512,573 Nm^3. It has a calorific value of 257,897,880 MJ. Assuming that the local CHP has an efficiency of power production of 40 % the annual electricity production can be calculated as 257,897,880 MJ $\cdot$0.40 : 3.6 kWh per MJ = 28,655,320 kWh.

Biogas based power production is subsidized with 0.411 DKK per kWh. So the production of 28,655,320 kWh increases government annual expenditures with 11.777 M DKK. In addition to this the local CHP plant receives tax exemption from both CO_2 tax and from tax on natural gas replaced for heat production. The tax rates are equal to 0.351 DKK and 0.742 DKK per Nm^3 of natural gas replaced at the CHP plant respectively – cf. Section 3.1. So, the total value of tax exemption can be calculated as 6,512,573 Nm^3 $\cdot$ (0.351 + 0.742) DKK per Nm^3 = 7.118 M DKK. This amount of money means a loss of income to the government.

In total the government annually loose a tax income of 18.895 M DKK to which is added the one-off construction subsidy of 17.5 M DKK. This amount is important for the welfare economic calculations, because it represents a so-called tax distortion loss. Of course, the subsidies and tax exemptions are also important for the financial calculations which inter alia show how the economic situation of biogas plant and local CHP plant is affected by the biogas production and use.

7.2 Welfare economic analysis

In Table 7.10 are shown the consequences, accounting prices and welfare economic value of consequences of biogas production based on 75 % pig slurry and 25 % maize at a biogas plant with a treatment capacity of 800 tonnes per day. It is seen from the table the total annual welfare economic value of biogas production is equal to - 20.38 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss 16.52 M DKK, - 0.14 M DKK and 4.00 M DKK are due to economic consequences, emission consequences and taxes and subsidies respectively. Especially loss of wheat production, transport, value of biogas and investment costs are important for the total result.

Subsidies and loss of taxes which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 4.00 M DKK to society. This is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases which are the occasion of so-called dead weight losses. The assumption of necessary tax increases to finance expenditures and tax losses is requested by the Danish Ministry of Finance in connection with welfare economic analyses, but the assumption can of be discussed – cf. Møller & Jensen (2004). Other financing possibilities which do not lead to dead weight losses are possible. If the financing problem is ignored production and use of biogas still lead to a welfare economic loss 16.38 M DKK.

Table 7.10 Calculation of welfare economic value of biogas production from 75 % pig slurry and 25 % maize at a biogas plant with a treatment capacity of 800 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 16.52
Agriculture – production			
- wheat production	- 15,145 tonnes	790 DKK per tonne ·1.17	- 14.00
- maize production	73,000 tonnes		
Agriculture – resource use			
- wheat seed	- 289 tonnes	2,800 DKK pr tonne· 1.17	0.95
- maize seed	3,403 pkg	700 DKK pr pkg· 1.17	- 2.79
- labour	795 hours	150 DKK pr hour· 1.17	- 0.14
- N fertilizer (synthetic and organic)	- 32 tonnes	7,500 DKK pr tonne· 1.17	0.28
- P fertilizer	20 tonnes	19,000 DKK pr tonne· 1.17	- 0.44
- K fertilizer	99 tonnes	9,000 DKK· 1.17	- 1.04
- plant protection	0.017 M DKK	0.017· 1.17	- 0.02
- fuel consumption (diesel)	10,269 litre	3.82 DKK pr litre· 1.17	- 0.05
- machine services	0.151 M DKK	0.151 ·1.17	- 0.18
- maintenance of machines	0.088 M DKK	0.088 ·1.17	- 0.10
Agriculture			
- synthetic fertilizer	278 tonnes	7,500 DKK pr tonne 1,17	2.44
Transport			
- slurry to biogas plant and residual product to farmers	365,000 km	15,22 DKK pr km	- 5.56
- export of wheat	- 37,861 km	15,22 DKK pr km	0.58
Biogas plant			
- biogas production for sale	6,512,573 Nm^3	1.8 DKK pr Nm^3 · 1.17	11.72
- electricity production for sale	5,876,770 kWh	0.46 DKK prkWh · 1.17	3.16
- investment costs	5.40 M DKK	5.40 M DKK 1.17	- 6.32
- labour	2 persons' work	320,000 DKK · 1.17	- 0.75
- electricity consumption	1,606,000 kWh	0.46 DKK pr kWh · 1.17	- 0.86
- water consumption	1,000 m^3	25 DKK pr m^3 · 1,17	- 0.03
- chemicals	25,000 DKK	25,000 DKK · 1.17	- 0.03
- service and maintenance	2,852,000 DKK	2,852,000 DKK · 1.17	- 3.34
Emission consequences			0.14
- CO_2 emissions [1]	- 16,135.630 + 1,917.576 tonnes	105 DKK pr tonne · 1.17	1.75
- N_2O emissions	4.244 tonnes	105 DKK pr tonne · 310 · 1.17	- 0.16
- CH_4 emissions	- 140.786 tonnes	105 DKK pr tonne · 21 · 1.17	0.36

Continued			
- C content of soil	- 461.215 tonnes	105 DKK pr tonne · 3,67· 1,17	- 0.21
- particle emissions	0.612 tonnes		
- NO_x emissions	28.681 tonnes	55,000 DKK pr tonne	- 1.58
- SO_2 emissions	5.515 tonnes	85,000 DKK pr tonne	- 0.47
- CO emissions	81.282 tonnes		
- NMVOC emissions	- 20.704tonnes		
- N-leaching	- 11.248 tonnes	40,000 DKK pr tonne	0.45
Public net income	- 19.98 M DKK	- 19.98 M DKK · 0,2	- 4.00
Total			-20.38

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK pr kWh · 1.17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 16,135.630 tonnes deducted reduced CO_2 emissions from alternative electricity production 1,917.576 tonnes.

Total annual amount of greenhouse gas emissions reductions, measured in CO_2 equivalents, associated with the scenario is: 16,135.630 tonnes - 4.244 tonnes 310 + 140.786 tonnes · 21 - 461.215 tonnes · 3,67 = 16,084 tonnes, and the value of this is equal to 1.98 M DKK, which primarily is due to biogas being regarded as a CO_2 neutral fuel. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 22.36 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case as high as 1,390 DKK per tonne CO_2 equivalent.

It is also seen from the table that the costs to society of reduced C content of soil and increased NO_x and SO_2 emissions (due to higher NO_x and SO_2 emission coefficients for biogas than for natural gas) almost correspond to the value of reduced climate gas emissions. Thus, from a welfare economic point of view biogas production at a 800 tonnes production plant based on 75 % pig slurry and 25 % maize does not seem to favourable.

Compared to biogas production based on 100 % pig slurry it is even worse. To a high extent this is due to the loss of wheat production, higher production costs of maize than of wheat and increased need of transport. The value of this loss is only partly compensated by the value of increased biogas production, further decrease in the need of N fertilizer and increased CO_2 emission reductions.

Below, the individual entries of the welfare economic account are explained in detail.

7.2.1 Value of economic consequences

The basis for estimation of accounting prices in welfare economic analysis is explained in Section 4.2.1. Therefore, only new prices compared to scenario 1A are explained below.

Agriculture

The market price of wheat and use of resources except diesel in agricultural production are all stated in Videncentret for landbrug (2010a). Market prices including not refundable taxes are increased with the net tax factor 1.17 to get accounting prices of the different resources. The accounting price of diesel is based on Energistyrelsen 2010. Here is stated an import price including distribution costs of 100.4 DKK per GJ, which is equal to 100.4 DKK per GJ · 40.65 GJ per tonne · 0.00085 tonne per litre = 3.82 DKK per liter. This price is increased with the net tax factor to get the accounting price of diesel.

Transport

The costs associated with increased transport are again calculated on the basis of the general distance dependent welfare economic cost of 3,7 DKK per km provided by the Department of Transport at the Danish Technical University (DTU) - cf. Danish Technical University (2010).

Biogas plant

The welfare economic value of biogas sold to a local CHP and the welfare economic costs of resource use are calculated as in scenario 1A - cf. Section 4.2.1.

7.2.2 Value of emission consequences

The value of emission consequences is calculated with the same welfare economic accounting prices as in scenario 1A - cf. Section 4.2.2.

7.2.3 Public net income – tax distortion loss

In Section 7.1.3 it was calculated that the public sector will loose annual tax income equal to 18.895 M DKK. To this must be added an investment subsidy of total 17.5 M DKK, which means an annual expenditure of 1.08 M DKK. - cf. Section 4.2.3. In total annual public net income will decrease with 19.98 M DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 4.0 M DKK.

7.3 Financial analysis

In Table 7.11 it is shown how the financial circumstances of the involved economic sectors are affected. It is seen from the table that the agricultural sector and the local CHP plant are economic winners while the biogas plant and the state both are losers. As previously mentioned, it is however important to bear in mind that this result at least to some extent is contingent upon the underlying assumptions about relative prices and about which sectors receive income and bear expenditure burden.

As an example it is assumed that the biogas plant pays the market price of 270 DKK per tonne for maize and bears the costs of 4.75 M DKK of transporting untreated and treated slurry as well as maize. Considering that the agricultural sector gets a profit of 7.31 M DKK because of higher net income from maize than from wheat and because of decreased need of synthetic fertilizer this sector might be able to sell the maize for a lower price and perhaps also bear some of the transport costs together with the local CHP plant.

If the agricultural sector and the local CHP plant pay some of the transport costs and the agricultural sector charge a price lower than the market prize for maize used for biogas production it might be possible to cover the economic loss of the biogas plant. However, in any case the state will lose tax income and have increased expenditures for subsidies and therefore, the production and use of biogas will inflict financial loses on at least one of the involved economic sectors.

Table 7.11 Calculation of financial consequences of biogas production from 75 % pig slurry and 25 % maize at a biogas plant with a treatment capacity of 800 tonnes per day – M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			7.31 M DKK
Production			
- wheat production	- 15,145 tonnes	790 DKK pr tonne	- 11.96 M DKK
- maize production	73,000 tonnes	270 DKK pr tonne	19.71 M DKK
Resource use			
- wheat seed	- 289 tonnes	2,800 DKK pr tonne	0.81 M DKK
- maize seed	3,403 pkg	700 DKK pr pkg	- 2.38 M DKK
- labour	795 hours	150 DKK pr hour	- 0.12 M DKK
- N fertilizer (synthetic and organic)	- 32 tonnes	7,500 DKK pr tonne	0.24 M DKK
- P fertilizer	20 tonnes	19,000 DKK pr tonne	- 0.38 M DKK
- K fertilizer	99 tonnes	9,000 DKK	- 0.89 M DKK
- plant protection	0.017 M DKK	0.017M DKK	- 0.02 M DKK
- fuel consumption (diesel)	10,269 liter	4.3 DKK pr litre	- 0.04 M DKK
- machine services	0.151 M DKK		- 0.15 M DKK
- maintenance of machines	0.088 M DKK		- 0.09 M DKK
- wheat export – transport	- 37,861 km	13.00 DKK pr km	0.49 M DKK
Fertilizer effect of treated slurry			
- demand for synthetic fertilizer	- 278 tonnes	7,500 DKK pr tonne	2.09 M DKK
Biogas plant			- 1.03 M DKK
- biogas production for sale	6,512,573 Nm^3 natural gas	4.4 DKK pr Nm^3	28.66 M DKK
- electricity production for sale	5,876,770 kWh	0.772 DKK pr kWh	4.54 M DKK
- investment costs	6.47 M DKK		- 6.47 M DKK
- construction subsidy	1.29 M DKK		1.29 M DKK
- labour	2 persons' work	320,000 DKK	- 0.64 M DKK
- maize consumption	73,000 tonnes	270 DKK pr tonne	- 19.71 M DKK
- electricity consumption	1,606,000 kWh	0.65 DKK pr kWh	- 1.04 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 dkk	- 0.03 M DKK
- service and maintenance	2,852,000 DKK	2,852,000 dkk	- 2,85 M DKK
- transport of slurry and residual	365,000 km	13.00 DKK pr km	- 4.75 M DKK
Local CHP plant			1.85 M DKK
- consumption of biogas	6,512,573 Nm^3 natural gas	4.4 DKK pr Nm^3	- 28.66 M DKK
- decreased consumption of natural gas	6,512,573 Nm^3 natural gas	1.782 DKK pr Nm^3	11.61M DKK
- biogas based power production	28,655,320 kWh. kWh	0.411 DKK pr kWh	11.78 M DKK
- CO_2 tax exemption	6,512,573 Nm^3 natural gas	0.351 DKK pr Nm^3	2.29 M DKK
- exemption from tax on natural gas for heat	6,512,573 Nm^3 natural gas	0.742 DKK pr Nm^3	4.83 M DKK
The state			- 20.19 M DKK
- construction subsidy	1.29 M DKK		- 1.29 M DKK
- biogas based power production	28,655,320 kWh. kWh	0.411 DKK pr kWh	- 11,78 M DKK
- CO_2 tax exemption	6,512,573 Nm^3 natural gas	0.351 DKK pr Nm^3	- 2.29 M DKK
- exemption from tax on natural gas for heat	6,512,573 Nm^3 natural gas	0.742 DKK pr Nm^3	- 4.83 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Of course the state can choose to accept its financial loses because of the large reduction in climate gas emissions which is the most important result of biogas production and use. However, as the welfare economic analysis has shown the value to society of these emission reductions is not big enough to justify the welfare economic costs of biogas production.

In the following section the financial calculations are explained in more detail.

7.3.1 Agriculture

It is seen from Table 7.11 that the agricultural sector annually gets a profit equal to 7.31 M DKK. The profit is due to higher net income form maize production than for wheat production and to decreased need for synthetic fertilizer when slurry is replaced by residual matter from the biogas production as fertilizer. The price of maize of 270 DKK pr tonne is based on a prize of 1.05 DKK pr FE stated in Videncentret for landbrug (2010a). The calculation assumes that 1 FE = 3.9 kg maize. As stated in the beginning of this chapter it is assumed the DM content of maize is 30 % and that 1 FE = 1.17 kg DM. All other prices and amounts in DKK are also based on Videncentret for landbrug (2010a).

7.3.2 Biogas plant

The biogas plant is expected to get an annual net deficit of 1.03 M DKK. The prices used in the calculations are factor prices including not refunded taxes which were the basis for determination of accounting prices in the welfare economic analysis – cf. Section 4.2.1. Yet the price of transport of 13.00 DKK per km is obtained by dividing the welfare economic accounting price of 15.22 DKK per km by the net-tax factor of 1.17. The financial result for the biogas plant is based on two important assumptions that have been discussed above.

For one it is assumed that the biogas plant pays the market price for maize. Alternatively it could have been assumed that maize for biogas production is trade to a lower price. This is a possibility because to the given prices the agricultural sector will earn a profit by substituting wheat production with maize production and use treated slurry as fertilizer in stead of synthetic fertilizer.

Secondly, it is assumed that the biogas plant pays for transport of slurry and maize from farmers to biogas plant and residual matter from the biogas plant to farmers. Alternatively it could have been assumed that transport is totally or partly paid by farmers because they earn a profit.

With regard to the assumptions about electricity prices and annual investment costs see Section 4.3.2 for further explanation.

7.3.3 Local CHP plant

If the assumption that the price which the local CHP plant pays for biogas is equal to the natural gas price is accepted the financial circumstances of the local CHP plant are only affected by the subsidy to biogas based power production and exemptions from CO_2 tax and tax on natural gas for heat production. Based on the same assumptions about subsidy to biogas based power production and tax exemption from CO_2 tax and biogas used for heat production as stated in Section 4.1.3 the local CHP plant earns an annual profit of 1.85 M DKK.

In total the local CHP plant will earn an annual profit equal to 18.90 M DKK by replacing natural gas with biogas. However, the precondition for this profit is that the plant can buy biogas for the same price as natural gas.

7.3.4 The State

The state has increasing expenditures because of the construction subsidy to the biogas plant and biogas based power production at the local CHP plant. In addition to this the state loses tax income from CO_2 tax and tax on natural gas for heat production. In total net expenditures of the state are increased with 20.19 M DKK.

8 Biogas production from 75 % conventional pig slurry and 25 % maize at 500 tonnes per day plant, scenario 2B

Scenario 2B is very similar to scenario 2A, the primary difference being the processing capacity of the biogas plant. In scenario 2B the daily input capacity of the plant is 500 tonnes, which is equivalent to an annual input of 182.500 tonnes. As slurry accounts for 75 % of the input the annual slurry input requirement is 136.875 tonnes, which is equivalent to the amount of slurry produced by 198.576 slaughter pigs (5.516 LU's). And for maize, the annual input requirement is 45.625 tonnes, which is equivalent to the amount of maize produced on 1.064 hectares. As before, it is assumed that the production of maize displace the production of wheat. The only other difference between scenarios 2A and 2B is the assumed average distance between the farms supplying the slurry and the biogas production plant; hence, as was the case for the 100 % slurry scenarios, the average distance is assumed to be 15 km for the 800 tonnes per day plants, whereas it assumed to be 10 km for the 500 tonnes per day plants.

8.1 Consequence description

All consequences associated with scenario 2B except 1) investment and operating costs, and 2) the costs of transporting input to biogas production (including transport related emissions) are directly proportional to the amount of input used for biogas production and can therefore be assessed by a simple downscaling of the changes estimated for scenario 2A. More specifically, the changes applying to scenario 1B are calculated by multiplying the changes assessed for scenario 2A by 0.625 (i.e. 500 tonnes per day/800 tonnes per day = 0.625).

The consequences of scenario 2B are listed in Table 8.1. For the consequences, which are assessed by simple downscaling, the relevant values for scenario 2B are simply listed in the table; for descriptions of the consequences and the approaches used to quantify them reference is made to the previous chapters. The transport related consequences and the investment and operating costs applying to scenario 2B are assessed in the following sections.

Table 8.1 Calculation of consequences of biogas production from 75 % pig slurry and 25 % maize silage at biogas plant with a treatment capacity of 500 tonnes per day.

Economic consequences	Consequence per year
Agriculture – production	
- wheat production	- 9,465 tonnes
- maize production	45,625 tonnes
Agriculture – resource use	
- wheat seed	- 181 tonnes
- maize seed	2,127 pkg
- labour	497 hours
- N fertilizer (synthetic and organic)	- 20 tonnes
- P fertilizer	13 tonnes
- K fertilizer	62 tonnes
- plant protection	0.011 M DKK
- fuel consumption (diesel)	6,418 litre
- machine services	0.095 M DKK
- maintenance of machines	0.055 M DKK
Agriculture	
- reduced demand for synthetic N fertilizer	- 174 tonnes
Transport	
- slurry and maize to biogas plant and residual	152,083 km
- export of wheat	- 23,663 km
Biogas plant	
- biogas production for sale	4,070,358 Nm^3
- electricity production for sale	3,672,981 kWh
- investment costs	63.3 M DKK (total amount)
- labour	1 persons' work
- electricity consumption	1,186,250 kWh
- water consumption	1,000 m^3
- chemicals	25,000 DKK
- service and maintenance	2,041,000 DKK

Emission consequences	Total tonnes	Agriculture tonnes	Biogas tonnes	Transport – biomass for biogas tonnes	Transport – displaced production tonnes
- CO_2 emissions	- 10,146.2693	17.0355	- 10,267.0816	122.8992	- 19.1224
- N_2O emissions	2.6495	3.173	0.2011	0.0044	-0.0007
- CH_4 emissions	- 87.99	- 94.2853	6.2860	0.0064	-0.001
- C content of soil	- 288.2591	-288.2591			
- particle emissions	12.1635	11.8000	0.3511	0.0147	- 0.0023
- NO_x emissions	17.4676	0.1504	16.5444	0.9152	-0.1424
- SO_2 emissions	3.4461	0.0005	3.4449	0.0008	-0.0001
- CO emissions	50.7275	84.623	50.5184	0.1475	-0.023
- NMVOC emissions	- 12.9515	0.0153	- 12.9862	0.0230	-0.0036
- N-leaching	- 7.0305	- 7.0305			

Taxes and subsidies	
Biogas plant	
- construction subsidy (20 pct.)	12.7 M DKK (total amount)
CHP plant	
- biogas based power production (subsidy)	- 7.36 M DKK
- CO_2 tax exemption	- 1.43 M DKK
- exemption from tax on natural gas for heat production	- 3.02 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in DKK are stated in 2009 prices.

Transport

As mentioned in the beginning of the chapter, the distance between the farms supplying the input and the biogas plant are assumed to be 10 km in scenario 2B. As in scenario 2A tank trucks with a capacity of 30 tonnes are used to transport the untreated slurry and the treated biomass while lorries are used to transport the untreated maize. With an annual slurry input of 0.75*182,500 tonnes = 136,875 tonnes and an annual maize input of 0.25*182,500 tonnes = 45,625 tones the total annual transport requirement is: (136,875 tonnes : 30 tonnes * 20 km) + 2 * (45,625 tonnes : 30 * 20 km) = 152,083 km.

The transport related emissions consequences of scenario 1B are assessed using the same emissions coefficients as in the previous scenarios, and the resulting emissions changes are listed in Table 8.1.

Investment and operating costs

The estimated investment costs for scenario 2B are listed in Table 8.3 where it is seen that total investment costs amount to 63.3 M DKK.. The only difference between the investment costs of scenario 1B and 2B are the costs related to storage and pre-treatment of maize.

Table 8.2 Calculation of iInvestment costs for biogas plant with a capacity of 500 tonnes per day and 75 % pig slurry and 25 % maize as input - M DKK, factor prices.

Buildings, roads, etc.	11.5
Storage facilities for maize	7.5
Pre-treatment of maize	2.0
Reactors, pipes, etc.	11.1
Gas scrubbers	4.7
CRS (Control, Regulation , Supervision system)	11.8
Pumps etc.	4.9
CHP	2.5
Building site	2.3
Investment costs (A1)	*58.3*
Gas pipeline	2.1
Projecting/planning costs (5 % of A1)	2.9
Total investment costs	*63.3*

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

In terms of operating costs it is assumed that operating the biogas plant includes employment of 1 skilled workman. In addition to this 1,186,250 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 1,000 m^3 water. Also different chemicals are needed with factor price value equal to 25,000 DKK. Finally annual service and maintenance costs of the biogas plant are set to 3.5 % of A1 which is equal to 2,041,000 DKK. The investment and operating cost calculations are based on Petersen (2010).

8.2 Welfare economic analysis

In Table 8.3 the welfare economic consequences associated with biogas production according to scenario 2B, their accounting prices, and their resulting welfare economic value are listed. The approaches used in the calculations are similar to those used in scenario 1A and 2A; hence, for specification of the calculation principles, reference is made to previous chapters. Here we solely present the results. It is seen from the table the total annual welfare economic value of biogas production is equal to – 12.25 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss, economic consequences account for 8.85 M DKK, emissions consequences for – 0.06 M DKK and taxes and subsidies for 2.52 M DKK.

Table 8.3 Calculated welfare economic value of biogas production from 75 % pig slurry and 25 % maize at a biogas plant with a treatment capacity of 800 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 8.85
Agriculture production			
- wheat production	- 9,465 tonnes	790 DKK pr tonnes ·1.17	- 8.75
- maize production	45,625 tonnes		
Agriculture – resource use			
- wheat seed	- 181 tonnes	2,800 DKK pr tonnes ·1.17	0.59
- maize seed	2,127 pkg	700 DKK pr pkg· 1.17	- 1.74
- labour	497 hours	150 DKK pr hour· 1.17	- 0.09
- N fertilizer (synthetic and organic)	- 20 tonnes	7,500 DKK pr tonne· 1.17	0.18
- P fertilizer	13 tonnes	19,000 DKK pr tonne ·1.17	- 0.29
- K fertilizer	62 tonnes	9,000 DKK· 1.17	- 0.65
- plant protection	0.011 M DKK	0.011· 1.17	- 0.01
- fuel consumption (diesel)	6,418 litre	3.82 DKK pr litre· 1.17	- 0.03
- machine services	0.095 M DKK	0.095· 1.17	- 0.11
- maintenance of machines	0.055 M DKK	0.055· 1.17	- 0.06
Agriculture			
- synthetic fertilizer	174 tonnes	7,500 DKK pr tonne 1,17	1.53
Transport			
- slurry to biogas plant and residual product to farmers	152,083 km	15,22 DKK pr km	- 2.31
- export of wheat	- 23,663 km	15,22 DKk pr km	0.36
Biogas plant			
- biogas production for sale	4,070,358 Nm^3	1.8 DKK pr Nm^3 ·1.17	8.57
- electricity production for sale	3,672,981 kWh	0.46 DKK pr kWh 1.17	1.98
- investment costs	3.9 M DKK	3.9 M DKK 1.17	- 4.56
- labour	1 persons' work	320,000 DKK ·1.17	- 0.37
- electricity consumption	1,860,250 kWh	0.46 DKK pr kWh ·1.17	- 0.64
- water consumption	1,000 m^3	25 DKK pr m^3 ·1,17	- 0.03
- chemicals	25,000 DKK	25,000 DKK ·1.17	- 0.03
- service and maintenance	2,041,000 DKK	2,041,000 DKK ·1.17	- 2.39
Emission consequences			0.06
- CO_2 emissions [1]	- 10,146.2693 + 1,786.468 tonnes	105 DKK pr tonne ·1.17	1.03
- N_2O emissions	2.6495 tonnes	105 DKK pr tonne · 310 ·1.17	- 0.1
- CH_4 emissions	- 87.99 tonnes	105 DKK pr tonne · 21 ·1.17	0.23
- C content of soil	- 288.2591 tonnes	105 DKK pr tonne · 3,67· 1,17	- 0.13
- particle emissions	12.1635 tonnes		
- NO_x emissions	17.4676 tonnes	55,000 DKK pr tonne	- 0.96
- SO_2 emissions	3.4461 tonnes	85,000 DKK pr tonne	- 0.29
- CO emissions	50.7275 tonnes		
- NMVOC emissions	- 12.9515 tonnes		
- N-leaching	- 7.0305 tonnes	40,000 DKK pr tonne	0.28
Public net income	- 12.59 M DKK	- 12.59 M DKK ·0,2	- 2.52
Total			- 11.31

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter. Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh · 1.17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 10,146.2693 tonnes deducted reduced CO_2 emissions from alternative electricity production 1,786.468 tonnes.

Total annual amount of greenhouse gas emissions reductions, measured in CO_2 equivalents, associated with the scenario is: 10,146.2693 tonnes - 2.6495 tonnes * 310 + 87.99 tonnes * 21 - 288.2591 tonnes * 3,67 = 10,115 tonnes, and the value of this is equal to 1.24 M DKK. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 12.55 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case as high as 1,241 DKK per tonne CO_2 equivalent.

8.3 Financial analysis

In Table 8.4 the results of the financial analysis pertaining to scenario 2B are presented. As was the case for the welfare economic analysis, reference is made to Chapter 4 for a detailed description of the principles applied in the calculations.

Table 8.4 Calcualtion of financial consequences of biogas production from 75 % pig slurry and 25 % maize at a biogas plant with a treatment capacity of 500 tonnes pr day - M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			4.55 M DKK
Production			
- wheat production	- 9,465 tonnes	790 DKK pr tonne	- 7.48 M DKK
- maize production	45,625 tonnes	270 DKK pr tonne	12.32 M DKK
Resource use			
- wheat seed	- 181 tonnes	2,800 DKK pr tonne	0.51 M DKK
- maize seed	2,127 pkg	700 DKK pr pkg	- 1.49 M DKK
- labour	497 hours	150 DKK pr hour	- 0.07 M DKK
- N fertilizer (synthetic and organic)	- 20 tonnes	7,500 DKK pr tonne	0.15 M DKK
- P fertilizer	13 tonnes	19,000 DKK pr tonne	- 0.25 M DKK
- K fertilizer	62 tonnes	9,000 dkk	- 0.56 M DKK
- plant protection	0.011 M DKK	0.017M DKK	- 0.01 M DKK
- fuel consumption (diesel)	6,418 litre	4.3 DKK pr litre	-0.03 M DKK
- machine services	0.095 M DKK		- 0.1 M DKK
- maintenance of machines	0.055 M DKK		- 0.06 M DKK
- wheat export – transport	- 23,663 km	13.00 DKK PR km	0.31 M DKK
Fertilizer effect of treated slurry			
- demand for synthetic fertilizer	- 174 tonnes	7,500 DKK pr tonne	1.31 M DKK
Biogas plant			- 0.47 M DKK
- biogas production for sale	4,070,358 Nm^3	4.4 DKK pr Nm^3	17.91 M DKK
- electricity production for sale	3,672,981 kWh	0.772 DKK pr kWh	2.84 M DKK
- investment costs	4.67 M DKK		- 4.67 M DKK
- construction subsidy	0.94 M DKK		0.94 M DKK
- labour	1 persons' work	320,000 DKK	- 0.32 M DKK
- maize consumption	45,625 tonnes	270 DKK pr tonne	- 12.32 M DKK
- electricity consumption	1,860,250 kWh	0.65 DKK pr kWh	- 0.77 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 DKK	- 0.03 M DKK
- service and maintenance	2,041,000 DKK	2,852,000 DKK	- 2.04 M DKK
- transport of slurry and residual	152,083 km	13.00 DKK pr km	- 1.98 M DKK
Local CHP plant			1.15 M DKK
- consumption of biogas	4,070,358 Nm^3 natural gas	4.4 DKK pr Nm^3	- 17.91 M DKK
- decreased consumption of natural gas	4,070,358 Nm^3 natural gas	1.782 DKK pr Nm^3	7.25 M DKK
- biogas based power production	17,909,575 kWh	0.411 DKK pr kWh	7.36 M DKK
- CO_2 tax exemption	4,070,358 Nm^3 natural gas	0.351 DKK pr Nm^3	1.43 M DKK
- exemption from tax on natural gas for heat	4,070,358 Nm^3 natural gas	0.742 DKK pr Nm^3	3.02 M DKK
The state			- 12.75 M DKK
- construction subsidy	1.14 M DKK		- 0.94 M DKK
- biogas based power production	17,909,575 kWh	0.411 DKK pr kWh	- 7.36 M DKK
- CO_2 tax exemption	4,070,358 Nm^3 natural gas	0.351 DKK pr Nm^3	- 1.43 M DKK
- exemption from tax on natural gas for heat	4,070,358 Nm^3 natural gas	0.742 DKK pr Nm^3	- 3.02 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

9 Biogas production from 75 % conventional pig slurry and 25 % maize at 50 tonnes per day plant, scenario 2C

Scenario 2C is similar to scenarios 2A and 2B in terms of the type of input used for biogas production; hence, input is comprised of 75 % pig slurry and 25 % maize. The daily input capacity of the plant is 50 tonnes, which is equivalent to an annual input of 13,688 tonnes of pig slurry and 4,563 tonnes of maize. This slurry input requirement is equivalent to the slurry production from 19,858 slaughter pigs (552 LU's), and the maize input requirement is equivalent to the yield from 106 hectares grown with maize.

The biogas plant considered in scenario 2C is a farm biogas plants, and therefore the scenario is in many ways similar to scenario 1C. Hence, as the plant is located on the farm, there is no transport requirement associated with getting the biomass from the farm to the biogas plant. In terms of the use of the biogas, it is – like in scenario 1C – assumed that all the biogas is used for the production of heat and electricity at a CHP unit on the biogas plant. Part of the energy production is used on the biogas plant, and 30 % of the excess heat production is assumed to be used on the farm where it substitutes oil-based heat production, while the remaining 70 % is lost. In terms of electricity, the entire production is sold to the net where it displaces "generic" electricity.

The agriculturally related effects of scenario 1C are similar to those of scenario 1A and 1B, only the scale is different due to the smaller treatment capacity of the facility.

In terms of emission changes, the fact that the biogas plant is located on the farm implies that there are no transport related emissions associated with scenario 1C. Instead emissions changes are induced by the changes in energy production related to the increased production of heat and electricity from biogas and the subsequent displacement of "generic electricity" and oil based heat production.

9.1 Consequence description

Many of the changes induced by biogas production are directly proportional to the amount of input used for biogas production. For these directly input related factors the changes induced by scenario 2C can be assessed by a simple downscaling of the changes estimated for scenario 2A and 2B. In other cases the situation pertaining to the farm biogas plant differs from that of the joint biogas plants and subsequently the consequences and the way to assess them also differs in some instances.

Table 9.1 contains a list of all the consequences associated with scenario 1C. All the agriculturally related effects of scenario 2C are directly proportional to scenarios 2A and 2B, and therefore the relevant values are listed in the table without further specification.

Table 9.1 Calculation of consequences of biogas production from 75 % pig slurry and 25 % maize silage at biogas plant with a treatment capacity of 50 tonnes per day.

	Consequence per year
Economic consequences	
Agriculture – production	
- wheat production	- 947 tonnes
- maize production	4,563 tonnes
Agriculture – resource use	
- wheat seed	- 18 tonnes
- maize seed	213 pkg
- labour	50 hours
- N fertilizer (synthetic and organic)	- 2 tonnes
- P fertilizer	1 tonnes
- K fertilizer	6 tonnes
- plant protection	0.001 M DKK
- fuel consumption (diesel)	642 litre
- machine services	0.009 M DKK
- maintenance of machines	0.005 M DKK
Agriculture	
- reduced demand for synthetic N fertilizer	- 17 tonnes
Transport	
- slurry and maize to biogas plant and - residual product to farmers	0 km
- export of wheat	- 2,366 km
Biogas plant	
- electricity production for sale (total production)	2,333,515 kWh
- heat production – displaced gasoil	2,902,319 MJ = 80,914 litre gasoil
- investment costs	10.6 M DKK (total amount)
- labour	365 hours
- electricity consumption	119,795 kWh
- water consumption	300 m^3
- chemicals	2,500 DKK
- service and maintenance	354,000 DKK

Emission consequences	Total, tonne	Agriculture, tonne	Biogas, tonne	Transport – biomass for biogas, tonne	Transport – displaced production, tonne
- CO_2 emissions	- 1,208.9406	1.7035	- 1,208.7319	0	- 1.9122
- N_2O emissions	0.2622	0.2448	0.0175	0	- 0.0001
- CH_4 emissions	0.4679	- 9.1489	8.6810	0	- 0.0001
- C content of soil	- 28.8259	- 28.8259			
- particle emissions	0.0085	0.0012	0.0075	0	- 0.0002
- NO_x emissions	3.2621	0.0150	3.2613	0	- 0.0142
- SO_2 emissions	0.1263	0.0001	0.1262	0	- 0.0000
- CO emissions	6.082	0.0085	6.0758	0	- 0.0023
- NMVOC emissions	0.079	0.0015	0.0779	0	- 0.0004
- N-leaching	- 0.7030	- 0.7030			

Taxes and subsidies	
On-site CHP plant	
- reduced demand for gas oil – energy tax	- 200,586 DKK
- reduced demand for gas oil – CO_2 tax	- 33,984 DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in DKK are stated in 2009 prices.

Below the consequences which cannot simply be assessed by simple downscaling of the results from scenario 2A and 2B are explained in more detail.

9.1.1 Economic consequences

Biogas production per tonne of input is slightly different for the farm biogas compared to the joint biogas plants. The reason for this being that the production process is assumed to be mesophile process rather than thermophile, and that the time that the biomass is in the biogas reactor is longer (50 days compared to 20). The key factors used to calculate biogas production per tonne of input for the farm biogas plant in scenario 2C are listed in Table 9.2.

A daily biomass input of 50 tonnes is equivalent to an annual biomass input of 18,250 tonnes, and with reference to Table 9.2 where the gas production per tonne of input is seen to be equal to 29.06 Nm^3 natural gas equivalents this implies that the gross annual production of the facility amounts to 530,345 Nm^3 natural gas equivalents. Using that the lower heating value of natural gas is 39.6 MJ per Nm^3 this is equivalent to a gross annual production of approximately 21,000,000 MJ.

Table 9.2 Calculation of biogas production per tonne of input (75 % pig slurry and 25 % maize at farm biogas plant).

	Pig slurry (75 % of input)	Maize (25 % of input)
Dry matter (DM) content	4.5 %	30 %
Kg DM pr tonne	45	300
VS/DM ratio [1]	0.8	0.95
Kg VS pr tonne [1]	36	285
Nm^3 CH_4 pr kg VS (HRT=50 days) [1]	0.29	0.34
Nm^3 CH_4 pr tonne	10.44	96.9
CH_4 content of biogas	60 %	60 %
Biogas production (Nm^3 pr tonne)	17.4	161.5
Heating value CH_4 (lower; MJ pr Nm^3)	35.9	35.9
Heating value Natural gas (lower; MJ pr Nm^3)	39.9	39.9
Ratio: Natural gas pr CH_4	1.1	1.1
Production in natural gas equivalents (Nm^3 tonne)	9.46	88.1
Production in natural gas equivalents (Nm^3 pr tonne of input (75 % pig slurry, 25 % maize))		29.06

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be decomposed.

In Table 9.3 the calculations of how the produced biogas is used is specified. The process heat requirement for scenario 2C is identical to that applying to scenario 1C.

Table 9.3 Specification of the use of biogas production.

Use	Share of gross production	Share in relevant energy equivalents
Gross energy production	100	530,344 Nm^3 Natural gas eq.
Process heat [1]	4.7	991,705 MJ
Electricity for sale [1,2]	40	2,333,515 kWh
Excess heat production [1, 3]	46.1	9,674,396 MJ

1. All heat and electricity production is assumed to be produced at a on-site CHP facility.
2. Electricity for sale is equal to gross electricity production.
3. Of the excess heat production only 30 % are assumed to be used; the remaining 70 % are assumed to be lost.

In contrast to the joint biogas plant scenarios where the biogas production in excess of what is needed to cover the process heat requirement is sold to a local CHP facility the entire biogas production is assumed to be used on the on-plant CHP for the farm biogas plants. The entire amount of electricity (2,333,515 kWh) produced at the CHP is sold. For the heat share of energy production, the heat production in excess of what is required for process heat is equal to 9,674,396 MJ. Of this excess heat production it is assumed that 30 % is put to use on the farm (e.g. for heating of stables and housing), while the remaining 70 % is lost. The 30 % of excess heat production replaces an amount of gasoil equal to 2,902,319 MJ · 0.30 : 35.87 MJ per litre = 80,914 litre gasoil

In Table 9.4 the investment costs for scenario 2C are listed. Following the approach used in the other scenarios the CHP related costs are based on a cost per MJ of 0.075 DKK. With a gross annual production of 530,344 Nm^3 Natural gas equivalents, which is equivalent to 21,001,635 MJ, estimated CHP investment costs becomes approximately 1.6 M DKK. The investment cost calculations are based on Petersen (2010).

Table 9.4 Calculation of iInvestment costs for farm biogas plant with a capacity of 50 tonnes per day and 75 % pig slurry and 25 % maize as input - M DKK, factor prices.

Storage facilities for maize	0.8
Pre-treatment of maize	0.5
CHP	1.6
Biogas plant	7.2
Investment costs (A1)	10.1
Projecting/planning costs (5 % of A1)	0.5
Total investment costs	10.6

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

As it appears from Table 9.1 the time required for operating the plant is set to 365 hours, and electricity consumption is set to 119,795 kWh. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 300 m^3 water. Also different chemicals are needed with factor price value equal to 2,500 DKK. Finally annual service and maintenance costs of the biogas plant are set to 3.5 % of A1, which is equal to 354,000 DKK. The operating cost calculations are based on Petersen (2010).

9.1.2 Emission consequences

The agriculturally related emissions of N_2O and CH_4 emissions from agriculture, and the changes in the C content of the soil and in N-leaching, are directly proportional to the amount of input used for biogas production. Hence, the effects pertaining to scenario 2C are equal to 1/10 of the effects pertaining to scenario 2B.

Emissions consequences related to biogas production and use

The more specific energy related emissions changes pertaining to scenario 2C are listed in Table 9.5. The assumptions underlying the calculations are similar to those applied in scenario 1C – see Section 6.1.2.

Table 9.5 Calculation of emissions changes from the changes in energy production caused by the production of biogas from 75 % pig slurry and 25 % maize at a farm biogas plant with a daily input capacity of 50 tonnes - tonne.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	TSP	NO_x	SO_2	CO	NMVOC
		EF (g pr MJ)	0.000	0.002	0.434	0.003	0.202	0.019	0.310	0.010
Biogas based CHP-production	Total production (21,001,635 MJ)	Change (tonne)	0.000	0.034	9.115	0.055	4.242	0.403	6.511	0.210
Reduced consumption of "generic"-electricity	Net electricity sale from biogas plant	EF (g pr MJ)	124.722	0.002	0.054	0.004	0.104	0.026	0.039	0.011
	(7,969,392 MJ)	Change (tonne)	-993.960	-0.014	-0.432	-0.033	-0.830	-0.210	-0.31	-0.089
Reduced use of oil for heat production[1]	Displaced oil-based heat prodcution (2,902,319	EF (g pr MJ)	74.000	0.001	0.001	0.005	0.052	0.023	0.043	0.015
	MJ)	Change (tonne)	-214.772	-0.002	-0.002	-0.015	-0.151	-0.067	-0.125	-0.044
	Total net change in emissions (tonne):		-1,208.732	0,018	8.681	0.008	3.261	0.126	6.076	0.078

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity), Nielsen et al. (2010) (biogas) and Danmarks Miljøundersøgelser (2011) (oil).

Note 1: It is assumed that 30 % of the excess heat production is used.

From Table 9.5 it is seen that overall the production of biogas and the associated changes in fuel use in energy production entail net increases in all emissions but CO_2.

9.1.3 Taxes and subsidies

In relation to taxes and subsidies, there is an important difference between the joint plant scenarios and scenario 1C. Hence, the 20 % construction subsidy does not apply to conventional farm biogas plants.

As 30 % of the excess heat production at the on-site CHP displaces gasoil consumption the state will lose tax income associated with the consumption of gasoil. More specifically, the government will loose income from a gasoil tax of 2.479 DKK per litre gasoil and a CO_2 tax of 0.42 DKK per litre gasoil. The amount of gasoil displaced in scenario 2C is equal to 80,914 litre and consequently the losses in tax income are estimated to 200,586 DKK (gasoil tax) and 33,984 DKK (CO_2 tax).

The total loss in tax income incurred by the government is 234,570 DKK.

9.2 Welfare economic analysis

In Table 9.6 the welfare economic consequences associated with biogas production according to scenario 2C, their accounting prices, and their resulting welfare economic value are listed. The approaches used in the calculations are similar to those used in scenario 1A; hence, for specification of the calculation principles, reference is made to Chapter 4. Here we solely present the results.

It is seen from the table the total annual welfare economic value of biogas production from 75 % pig slurry and 25 % maize at a biogas plant with a treatment capacity of 50 tonnes per day is equal to - 0.8 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss, economic consequences account for 0.6 M DKK, emissions consequences for 0.15 M DKK and taxes and subsidies for 0.05 M DKK.

The total annual reduction in greenhouse gas emissions brought about by the scenario is: (1,208.941- 0.262 *310 + 0.468 * 21 – 28.826 * 3.67) tonnes = 1,012.1 tonnes CO_2 equivalents, and the value of this reduction is equal to 0.12 M DKK. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 0.92 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case 909 DKK per tonne CO_2.

Below, the individual entries of the welfare economic account are explained.

Table 9.6 Calculation of welfare economic value of biogas production from 75 % pig slurry and 25 % maize at a farm biogas plant with a treatment capacity of 50 tonnes pr day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			-0.6
Agriculture – production			
- wheat production	- 947 tonnes	790 DKK pr tonne ·1.17	-0.88
- maize production	4,563 tonnes		
Agriculture – resource use			
- wheat seed	- 18 tonnes	2,800 DKK pr tonne ·1.17	0.06
- maize seed	213 pkg	700 Dkk pr pkg·1.17	-0.17
- labour	50 hours	150 DKK pr hour·1.17	-0.01
- N fertilizer (synthetic and organic)	- 2 tonnes	7,500 DKK pr tonne·1.17	0.01
- P fertilizer	1 tonnes	19,000 DKK pr tonne·1.17	-0.02
- K fertilizer	6 tonnes	9,000 DKK·1.17	-0.06
- plant protection	0.001 M DKK	0.001·1.17	-0.00
- fuel consumption (diesel)	642 litre	3.82 DKK pr litre·1.17	-0.00
- machine services	0.009 M DKK	0.009·1.17	-0.01
- maintenance of machines	0.005 M DKK	0.005·1.17	-0.01
Agriculture			
- synthetic fertilizer	- 17 tonnes	7,500 DKK pr tonne · 1,17	0.15
Transport			
- export of wheat	- 2,366 km	15,22 DKK pr km	0.04
Biogas plant			
- electricity production for sale	2,333,515 kWh	0.46 DKK pr kWh · 1.17	1.26
- heat production – displaced gasoil	2,902,319 MJ = 80,914litre	110 DKK pr GJ · 1.17	0.37
- investment costs	0.5 M DKK.	0.5 M DKK · 1.17	-0.76
- labour	365 hours	200 DKK · 1.17	- 0.09
- electricity consumption	119,795 kWh	0.46 DKK pr kWh · 1.17	- 0.06
- water consumption	300 m^3	25 DKK pr m^3 · 1,17	- 0.01
- chemicals	2.500 DKK	2.500 DKK · 1.17	- 0.00
- service and maintenance	354,000 DKK	354,000 DKK · 1.17	- 0.41
Emission consequences			-0.15
- CO_2 emissions [1]	- 1,208.941 + 999.96 tonnes	105 DKK pr tonne· 1.17	0.03
- N_2O emissions	0.262 tonnes	105 DKK pr tonne· 310 1.17	-0.01
- CH_4 emissions	0.468 tonnes	105 DKK pr tonne · 21 · 1.17	-0.00
- C content of soil	- 28.826 tonnes	105 DKK pr tonne · 3,67· 1,17	- 0.01
- particle emissions	0.009 tonnes		
- NO_x emissions	3.262 tonnes	55,000 DKK pr tonne	-0.18
- SO_2 emissions	0.126 tonnes	85,000 DKK pr tonne	-0.01
- CO emissions	6.082 tonnes		
Continued			
- NMVOC emissions	0.079 tonnes		
- N-leaching	- 0.703 tonnes	40,000 DKK pr tonne	0.03
Public net income	- 234,570 DKK	-234,570 DKK · 0,2	- 0.05
Total			- 0.80

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.
Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh · 1.17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 1,208.941 tonnes deducted reduced CO_2 emissions from alternative electricity production 999.96 tonnes.

9.2.1 Value of economic consequences

Generally accounting prices of economic consequences are determined as for scenario 1A – cf. Section 4.2.1 – and scenario 1C (gasoil) – cf. Section 6.2.1.

9.2.2 Value of emission consequences

With regard to determination of accounting prices for emission consequences refer to Section 4.2.2.

9.2.3 Public net income – tax distortion loss

In Section 6.1.3 it was calculated that the public sector will loose annual tax income equal to 234,570 DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 0.05 M DKK.

9.3 Financial analysis

In Table 9.7 the results of the financial analysis pertaining to scenario 2C are presented. Reference is made to Section 4.3 and 6.3 for more detailed descriptions of the principles applied in the calculations.

The annual investment costs of 0.78 M DKK are determined by annualizing the investment costs of 10.6 M DKK over a 25 years life time of the plant and an interest rate of 6 %.

Table 9.7 Calculation of financial consequences of biogas production from 75 % pig slurry and 25 % maize at a farm biogas plant with a treatment capacity of 50 tonnes per day - M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			0.45 M DKK
Production			
- wheat production	- 947 tonnes	790 DKK pr tonne	- 0.75 M DKK
- maize production	4,563 tonnes	270 DKK pr tonne	1.23 M DKK
Resource use			
- wheat seed	- 18 tonnes	2,800 DKK pr tonne	0.05 M DKK
- maize seed	223 pkg	700 DKK pr pkg	- 0.16 M DKK
- labour	50 hours	150 DKK pr hour	- 0.01 M DKK
- N fertilizer (synthetic and organic)	- 2 tonnes	7,500 DKK pr tonne	0.02 M DKK
- P fertilizer	1 tonnes	19,000 DKK pr tonne	- 0.02 M DKK
- K fertilizer	6 tonnes	9,000 DKK	- 0.05 M DKK
- plant protection	0.001 M DKK	0.001 M DKK	- 0.00 M DKK
- fuel consumption (diesel)	642 litre	4.3 DKK pr litre	-0.00 M DKK
- machine services	0.009 M DKK		- 0.01 M DKK
- maintenance of machines	0.005 M DKK		- 0.01 M DKK
- wheat export – transport	- 2,366 km	13.00 DKK pr km	0.03 M DKK
Fertilizer effect of treated slurry			
- demand for synthetic fertilizer	17 tonnes	7,500 DKK pr tonne	0.13 M DKK
Biogas plant			- 0.15 M DKK
- electricity production for sale	2,333,515 kWh	0.772 DKK pr kWh	1.8 M DKK
- heat production – displaced gasoil	2,902,319 MJ = 80,914 litre	6.845 DKK pr litre	0.55 M DKK
- investment costs	0.78 M DKK		- 0.78 M DKK
- labour	365 hours	150 DKK pr hour	- 0.05 M DKK
- maize consumption	4,563 tonnes	270 DKK pr tonne	- 1.23 M DKK
- electricity consumption	119,795 kWh	0.65 DKK pr kWh	- 0.08 M DKK
- water consumption	300 m^3	25 DKK pr m^3	- 0.01 M DKK
- chemicals	2,500 DKK	2,500 DKK	- 0.00 M DKK
- service and maintenance	354,000 DKK	354,000 DKK	- 0.35 M DKK
The state			- 0.23 M DKK
- reduced demand for gas oil – energy tax	200,586 DKK		- 0.2 M DKK
- reduced demand for gas oil - CO_2 tax	33,984 DKK		- 0,03 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

10 Scenario 3A: Biogas production from 100 % organic cattle slurry at 800 tonnes per day plant

In scenario 3A biogas production takes place at joint biogas plant with a treatment capacity of 800 tonnes per day and slurry from organic dairy herds constitute 100 % of the input. A daily input of 800 tonnes is equivalent to an annual input of 292,000 tonnes. The norm dry matter content of cattle slurry is 10 %, but in the present analyses it is set to 8 % in order to reflect the fact that the dry matter content in practice most often is found to be lower than the norm. Adjusting for lower dry matter content the annual slurry production per dairy cow is 26.9 tonnes implying that the annual input requirement is equal to the amount of slurry produced by 10,855 dairy cows. These calculations are based on the Danish stock of organic dairy cattle which consist of 89 % animals of a heavy race and 11 % jersey cattle. Using a conversion factor of 0.8 this is equivalent to 14,189 LU's per biogas plant.

In relation to the assumptions made regarding transport of biomass, use of the produced biogas and transport related emissions scenario 3A is similar to scenario 1A where input was 100 % pig slurry.

In contrast to scenario 1A there are no reductions in the need for application of synthetic fertiliser and no subsequent reductions in N-leaching associated with biogas production in scenario 3A. Hence, as the slurry is organic, it is assumed to be used as fertiliser in organic agriculture where synthetic fertiliser cannot be used. This implies that slurry and synthetic fertiliser cannot substitute for one another and consequently, the improved plant availability of N in treated slurry compared to untreated slurry does not translate into a reduction in the need for synthetic fertiliser. In stead it translates into an increase in yield. Apart from this yield effect the biogas treatment of slurry give rise to changes in the emissions of CH_4 and N_2O just as it has implications in relation to the C-content of the soil.

In addition to the agriculturally related emissions changes the increased transport requirement associated with the transportation of biomass to and from the biogas plant along with the substitutions induced in the energy production sector also gives rise to emissions changes.

10.1 Consequence description

In Table 10.1 the consequences of biogas production from 100 % organic cattle slurry at a biogas plant with a treatment capacity of 800 tonnes per day are summarized. The table is divided in three parts covering economic consequences, emissions and taxes and subsidies respectively. Economic consequences include the consequences for production and use of material input of re-allocating society's scarce resources. Emissions include the consequences for the discharge of different matters into the environment of the resource re-allocation. Taxes and subsidies concern the consequences for the State's net income of subsidizing biogas production through direct investment support and exemption from tax payments when energy production is based on biogas.

Table 10.1 Calculatio of consequences of biogas production from 100 % organic cattle slurry at biogas plant with a treatment capacity of 800 tonnes per day.

Economic consequences				Consequence per year
Agriculture – production (increased production following improved plant availability of N in treated slurry)				
- barley production				3,677 hkg
- triticale production				3,677 hkg
- grass clover production				755,051 FE
Transport				
- slurry to biogas plant and residual product to farmers				292,000 km
Biogas plant				
- biogas production for sale (natural gas equivalents)				1,798,622 Nm^3
- electricity production for sale				5,876,770 kWh
- investment costs				72.5 M DKK (total amount)
- labour				2 persons' work
- electricity consumption				1,606,000 kWh
- water consumption				1,000 m^3
- chemicals				25,000 DKK
- service and maintenance				2,345,000 DKK
Emission consequences (tonnes)	Total (tonne)	Agriculture, (tonne)	Biogas; (tonne)	Transport, (tonne)
- CO_2	- 5,725.075		- 5,961.0429	235.9675
- N_2O	- 21.431	- 21.5729	0.1295	0.0085
- CH_4	- 258.614	- 277.400	18.7743	0.0123
- C content of soil	- 788.400	-788.40		
- particles	0.236		0.2082	0.0281
- NO_x	15.612		13.8545	1.7572
- SO_2	1.958		1.9559	0.0015
- CO	34.030		33.7471	0.2831
- NMVOC	- 5.438		- 5.4824	0.0442
- N-leaching	-	-	-	-
Taxes and subsidies				
Biogas plant				
- construction subsidy (20 pct.)				14.5 M DKK (total amount)
CHP plant				
- biogas based power production (subsidy)				- 3.253 M DKK
- CO_2 tax exemption				- 0.631 M DKK
- exemption from tax on natural gas for heat production				- 1.335 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in DKK are stated in 2009 prices

Below the individual consequences are explain in more detail.

10.1.1 Economic consequences

Agriculture

In the pig slurry scenarios the biogas treatment of slurry entailed reductions in the demand for synthetic fertiliser and subsequent reductions in the level of N-leaching. Such effects do not arise in scenario 3A due to the fact that the slurry is organic and that focus therefore is on organic agriculture where synthetic fertiliser cannot be used. Hence, in scenario 3A the effect resulting from the improved plant availability of N in treated slurry (compared to untreated slurry) is an increase in yield rather than a decrease in the use of synthetic fertiliser (while keeping the yield constant). More specifically, the increase in yield is the result of the fact that the biogas treatment of slurry results in an increase in the ammonium share of N in slurry.

Based on the norm N-content of cattle slurry specified in Poulsen (2009) and adjusting this for the lower DM content used in the present analysis the N content of cattle slurry is 4.70144 kg per tonne. In scenario 3A where the total annual slurry input is 292,000 tonnes the total amount of N in the treated slurry is 1,372.82 tonnes. Assuming that the level of N application is 122 kg per ha this implies that the amount of slurry treated in the biogas plant is equivalent to the amount of slurry needed as fertiliser on 1,372.82 tonnes: 0.122 tonne per ha = 11,252.6 ha. The increase in yield brought about by the biogas treatment of the slurry is therefore assumed to apply to the agricultural production on 11,252.6 ha.

For cereal crops it is assumed that yield increases by 0.1071428 hkg per kg ammonium-N made available. Moreover, it is assumed that the biogas treatment of slurry implies that the share of ammonium-N increases by 10 % of total-N. With reference to an assumed N-application level of 122 kg N per ha this translates into an increase in ammonium N of 12.2 kg per ha. As the increase in yield is assumed to occur on 11,252.6 ha the total potential increase in yield – provided that cereal crops are grown on the entire affected area - is: 11,252.6 ha · 12.2 kg ammonium-N per ha · 0.1071428 hkg per kg ammonium-N = 14,708.7 hkg.

In terms of the type of crops grown on the areas fertilised with the treated biomass it is assumed that grass clover is grown on 50 % of the areas while spring barley and triticale each are grown on half of the remaining area - i.e. 25 % of each cereal. Hence, the calculated yield increase for cereal crops only applies to half of the affected area. For both cereal crops triticale and spring barley the expected yield increases with 14,708.7 hkg · 0.25 = 3,677 hkg.

For grass clover the yield is assumed to increase by 11 FE when the availability of ammonium-N is increased by 1 kg. As grass clover is assumed to be grown on half of the affected area – i.e. 11,252.6 ha · 0.50 = 5,626.3 ha and as the increase in ammonium N is assumed to be 12.2 kg per ha the total increase in ammonium-N is 68,640.9 kg. Multiplying this with the expected yield increase of 11 FE per kg ammonium-N we get the increase of 755,050 FE in the yield of grass clover resulting from the use of treated as opposed to untreated slurry as fertiliser.

Transport

The total demand for transport associated with the transport of slurry to and from the biogas plant in scenario is identical to that of scenario 1A, where the input also consists of 100 % slurry. Hence, the total demand for transport is 292,000 km.

Biogas plant

The norm dry matter (DM) content of cattle slurry is 10.3 % but as was the case for pig slurry the DM used in the present analyses DM is set somewhat lower in order to reflect the DM likely to occur in practice. More specifically, the DM for cattle slurry is set to 8 %. The key factors used to calculate biogas production per tonne of cattle slurry are listed in Table 10.2. As it is seen in the last row of the table the gas production measured in natural gas equivalents is 10.8 Nm^3 per tonne cattle slurry.

Table 10.2 Calculation of biogas production per tonne of cattle slurry input.

Dry matter (DM) content of cattle slurry	8 %
Kg DM per tonne cattle slurry	80
VS/DM ratio [1]	0.8
Kg VS per tonne cattle slurry [1]	64
Nm^3 CH_4 per kg VS (HRT=20 days)	0.185
Nm^3 CH_4 per tonne cattle slurry	11.84
CH_4 content of biogas	60 %
Biogas production (Nm^3 per tonne cattle slurry)	19.7
Heating value CH_4 (lower; MJ per Nm^3)	35.9
Heating value Natural gas (lower; MJ per Nm^3)	39.9
Ratio: Natural gas/CH_4	1.1
Production in natural gas equivalents (Nm^3 per tonne cattle slurry)	10.8

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be decomposed.

The annual biomass input is 292,000 tonnes and with a biogas production of 10.8 Nm^3 natural gas equivalents per tonne biomass input this implies that the gross annual production of the facility amounts to 3,134,251 Nm^3 natural gas equivalents. Using that the lower heating value of natural gas is 39.6 MJ per Nm^3 this is equivalent to a gross annual production of 124,116,352 MJ.

In Table 10.3 it is specified how the produced biogas is used. It can be seen form the table that of a total production of 3,134,251 Nm^3 natural gas equivalents biogas about 57 % of it 1,798,622 Nm^3 (71,225,419 MJ) can be sold to a local CHP plant. The reason for this is the need of process heat for biogas production. The heat is as in scenario 1 and 2 assumed to be supplied from an on-plant CHP facility, which uses biogas as fuel. The necessary amount of heat 31,734,560 MJ and the amount of electricity produced together with heat 5,876,770 kWh are also unchanged from these scenarios.

Table 10.3 Calculation of biogas production.

	Share of gross production (%)	Share in relevant energy equivalents
Gross energy production	100.0	3,134,251 Nm^3 Natural gas eq.
Process heat [1]	25.6	31,734,560 MJ
Electricity for sale [1]	17.0	5,876,770 kWh
Biogas for sale	57.4	1,798,622 Nm^3 natural gas eq.

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: 1. Process heat and electricity for sale is assumed to be produced at an on-site CHP facility.

Investment costs and use of economic resources in the production process are the same as in scenario 1A. These economic consequences are described in detail in Section 4.1.1. Maintenance costs are also assumed identical to those of scenario 1A.

10.1.2 Emission consequences

The total emission consequences stated in Table 10.1 are the result of the resource re-allocations described in Section 10.1.1 and like these they can be related to agriculture, transport and biogas production and use respectively.

The consequences of these three activities are summarized in Table 10.4. It is seen that climate gas emissions in total will decrease even if the C content of soil decreases and thereby neutralize some of the positive effect. All other emissions to air increase primarily because of increased demand for transport. N-leaching will not be affected because cattle slurry is regarded as an organic fertilizer and therefore do not replace synthetic fertilizer.

Table 10.4 Calculation of emission consequences of biogas production from 100 % cattle slurry at biogas plant with a treatment capacity of 800 tonnes per day – tonne.

Activities	CO_2	N_2O	CH_4	C content of soil	Particles	NO_x	SO_2	CO	NMVOC	N-leaching
Agriculture		- 21.57	- 277.40	- 788.40						-
Transport	235.968	0.009	0.012		0.028	1.757	0.002	0.283	0.044	
Biogas production and use	- 5,961.043	0.13	18.774		0.208	13.855	1.956	33.747	- 5.482	
Total	-5,725.075	-21.431	-258.614	-788.400	0.236	15.612	1.958	34.030	-5.438	-

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Below the different emission changes are explained in more detail.

Emission consequences related to agriculture

In the present section are assessed the consequences for N_2O emissions, CH_4 emissions, C-content of the soil and N-leaching induced by the changed use of cattle slurry.

As was the case for the pig slurry scenarios N_2O emissions from cattle slurry are also affected by the biogas treatment. More specifically the N_2O-N emissions coefficients for cattle slurry applied to JB1-3 soils in April are 2 % for untreated slurry and 1 % for treated slurry (see Appendix I). Hence the difference in N_2O-N emissions between the biogas scenario and the reference situation is 1 % of the total N-content of the slurry. With the N-content of cattle slurry set to 4.70144 kg per tonne - c.f. Section 10.1.1 - and an annual slurry input of 292,000 tonnes the total amount of N in the treated slurry amounts to 1,373 tonnes. This implies that the reduction in N_2O-N emissions is 13.73 tonnes. This is equivalent to a reduction in N_2O emission of 21.57 tonnes using the conversion factor of 44/28 between N_2O-N and N_2O.

As the production of biogas based on organic cattle slurry is assumed not to entail any changes in the demand for synthetic fertiliser, there are no fertiliser related changes in the level of N_2O emissions associated with the cattle slurry scenarios.

For cattle slurry biogas treatment is assumed to reduce CH_4 emissions by 0.95 kg per tonne of slurry (Møller & Olesen, 2011). In the present scenario where the annual input of slurry is 292,000 tonnes the resulting reduction in CH_4 emissions is 277.4 tonnes.

As was the case for pig slurry the use of cattle slurry for biogas production prior to field application leads to a reduction in the carbon content of the soil (soil C). More specifically, the reduction in soil C resulting from biogas treatment of cattle slurry is estimated to be 33.75 kg C per tonne of dry matter in the slurry (Coleman & Jenkinson, 1996; Sørensen, 1987; Olesen, 2011). In the present analyses the dry matter content of cattle slurry is set to 8 %, which is equivalent to assuming an absolute dry matter (DM) content of 80 kg DM per tonne of slurry. With a total annual slurry input of 292,000 tonnes the total amount of dry matter in the slurry is 292,000 tonnes slurry 0.080

tonnes DM per tonne slurry = 23,360 tonnes DM and the resulting reduction in soil-C can be calculated as 23,360 tonnes DM · 0.03375 tonne C per tonne DM = 788.4 tonnes C.

As the scenario does not entail any changes in the application of synthetic fertiliser application there are no changes between the biogas scenario and the reference situation in relation to the level of N-leaching.

Emission consequences related to transport

The total demand for transport associated with the transport of slurry to and from the biogas plant in scenario is identical to that of scenario 1A. Hence, the total demand for transport is 292,000 km and therefore, the emission changes related to transport are the same as in scenario 1A – cf. Section 4.1.2.

Emissions consequences related to biogas production and use

The emission changes related to biogas production and use can be calculated following the same method and using the same emission coefficients as in scenario 1A – cf. Section 4.1.2. The total production of biogas and amount of biogas sold to the local CHP plant are just different from scenario 1A. The different emission changes are summarized in Table 10.5.

Table 10.5 Calculation of emissions changes from the changes in energy production caused by the production of biogas from 100 % cattle slurry at a joint biogas plant with a daily input capacity of 800 tonnes.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	Particles	NO_x	SO_2	CO	NMVOC
Biogas based CHP-production	Total production (124,116,352 MJ)	EF (g pr MJ)	0.00	0.00	0.43	0.00	0.20	0.02	0.31	0.01
		Change (tonne)		0.199	53.867	0.326	25.072	2.383	38.476	1.241
Reduced produc-tion of electricity with coal as fuel	Net electricity sale from biogas plant (15,374,773 MJ)	EF (g per MJ)	124.72	0.00	0.05	0.00	0.10	0.03	0.04	0.01
		Change (tonne)	-1,917.576	-0.028	-0.833	-0.064	-1.602	-0.406	-0.598	-0.171
Reduced use of natural gas at local CHP	Biogas sold to local CHP (71,225,419 MJ)	EF (g pr MJ)	56.77	0.0006	0.48	0.00	0.14	0.00	0.06	0.09
		Change (tonne)	-4,043.467	-0.041	-34.259	-0.054	-9.615	-0.021	-4.131	-6.553
Total net change in emissions (tonne):			-5,961.043	0.130	18.774	0.208	13.855	1.956	33.747	-5.482

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity) and Niel-sen et al. (2010) (biogas and natural gas).

From Table 10.5 it is seen that overall the production of biogas and the associated changes in fuel use in energy production entail net increases in the emissions of N_2O, CH_4, particles, NO_x, SO_2 and CO while it results in net reductions in the emissions of CO_2 and NMVOC.

10.1.3 Taxes and subsidies

The production and use of biogas result in a re-allocation of society´s scarce resources which, as can be seen from Table 10.1, affects government finances.

First biogas production is subsidized directly with a subsidy of 20 % of the total investment cost of 72.5 M DKK. This means a governmental expenditure of 14.5 M DKK.

Second use of biogas at the local CHP plant is also subsidized in different ways which depends on the amount of power produced and amount of biogas replaced – see Section 3.1. The amount of biogas produced which replaces natural gas at the local CHP is equal to 1,798,622 Nm^3. It has a calorific value of 71,225,419 MJ. Assuming that the local CHP has an efficiency of power production of 40 pct. the annual electricity production can be calculated as 71,225,419 MJ $\cdot$ 0.40 : 3.6 kWh per MJ = 7,913,935 kWh.

Biogas based power production is subsidized with 0.411 DKK. per kWh. So the production of 7,913,935 kWh increases government annual expenditures with 3,252,627 DKK. In addition to this the local CHP plant receives tax exemption from both CO_2 tax and from tax on natural gas replaced for heat production. The tax rates are equal to 0.351 DKK and 0.742 DKK per Nm^3 of natural gas replaced at the CHP plant respectively – cf. Section 3.1. So, the total value of tax exemption can be calculated as 1,798,622 Nm^3 (0.351 + 0.742) DKK per Nm^3 = 1,965,894 DKK. This amount of money means a loss of income to the government.

10.2 Welfare economic analysis

In Table 10.6 are shown consequences, accounting prices and welfare economic value of consequences aof biogas production from 100 % cattle slurry at a biogas plant with a treatment capacity of 800 tonnes per day. It is seen that the biogas production results in a welfare economic loss to society of 5.76 M DKK. Of the total loss 5.11 M DKK, - 0.57 M DKK and 1.22 M DKK are due to economic consequences, emission consequences and taxes and subsidies respectively. Especially transport and investment costs are important for the total result.

Subsidies and loss of taxes which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 1.22 M DKK to society. This is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases which are the occasion of so-called dead weight losses. Other financing possibilities which do not lead to dead weight losses are possible. If the financing problem is ignored production and use of biogas still lead to a welfare economic loss of 4.54 M DKK.

The total reduction, measured in CO_2 equivalents, in GHG emissions entailed by the scenario is equal to: (5,725.075 + 21.431 $\cdot$ 310 + 258.614 $\cdot$ 21 – 788.4 $\cdot$ 3.67) tonne = 14,906 tonnes. The value of this reduction is equal to 1.83 M DKK; this value can be attributed to biogas being regarded as a CO_2 neutral fuel, and the fact that the treatment of cattle slurry for biogas production reduces N_2O and CH_4 emissions . If this value is subtracted from the total welfare economic costs of biogas production, an estimate is obtained of the welfare economic cost that society will have to pay to obtain the climate gas emission reduction. More specifically, it appears that it will cost society a welfare economic loss of 7.59 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case 509 DKK per tonne CO_2.

Table 10.6 Calculation of welfare economic value of biogas production from 100 % cattle slurry at a biogas plant with a treatment capacity of 800 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 5.11
Agriculture – production			
- barley production	3,677 hkg	100 DKK pr hkg · 1.17	0.43
- triticale production	3,677 hkg	100 DKK pr hkg · 1.17	0.43
- grass clover production	755,055 FE	1.30 DKK pr FE · 1.17	1.15
Transport			
- slurry to biogas plant and residual product to farmers	292,000 km	15,22 DKK pr km	- 4.44
Biogas plant			
- biogas production for sale	1,798,622 Nm^3	1.8 DKK pr Nm^3 · 1.17	3.79
- electricity production for sale	5,876,770 kWh	0.46 DKK pr kWh · 1.17	3.16
- investment costs	4.46 M DKK.	4.46 M DKK · 1.17	- 5.22
- labour	2 persons' work	320,000 DKK · 1.17	- 0.75
- electricity consumption	1,606,000 kWh	0.46 DKK pr kWh · 1.17	- 0.86
- water consumption	1,000 m^3	25 DKK pr m^3 · 1,17	- 0.03
- chemicals	25,000 DKK	25,000 DKK · 1.17	- 0.03
- service and maintenance	2,345,000 DKK	2,345,000 DKK · 1.17	- 2.74
Emission consequences			0.57
- CO_2 emissions [1]	- 5,725.075 + 1,917.58	105 DKK pr tonne · 1.17	0.47
- N_2O emissions	- 21.431 tonnes	105 DKK pr tonne · 310 · 1.17	0.82
- CH_4 emissions	- 258.614 tonnes	105 DKK pr tonne · 21 · 1.17	0.67
- C content of soil	- 788.400 tonnes	105 DKK pr tonne · 3,67· 1,17	- 0.36
- particle emissions	0.236 tonnes		
- NO_x emissions	15.612 tonnes	55,000 DKK pr tonne	- 0.86
- SO_2 emissions	1.958 tonnes	85,000 DKK pr tonne	- 0.17
- CO emissions	34.030 tonnes		
- NMVOC emissions	- 5.438 tonnes		
Public net income	6.11 M DKK	6.11 M DKK · 0,2	- 1.22
Total			- 5.76

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh · 1.17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 5,725.075 tonnes deducted reduced CO_2 emissions from alternative electricity production 1,917.576 tonnes.

It is also seen from the table that the costs to society of reduced C content of soil and increased NO_x and SO_2 emissions (due to higher NO_x and SO_2 emission coefficients for biogas than for natural gas) almost correspond to the value of reduced climate gas emissions. Thus, from a welfare economic point of view biogas production at an 800 tonnes production plant based on 100 % cattle slurry does not seem to favourable.

Below, the individual entries of the welfare economic account are explained in detail.

10.2.1 Value of economic consequences

Agriculture

The market prices of barley as well as triticale are stated in Videncentret for landbrug (2009) as 100 DKK per hkg. This price is multiplied with the net tax factor to get the accounting price of 117 DKK per hkg. As the production increase of both these crops is 3,677 hkg the value of production increases is 0.43 M DKK each. In Videncentret for landbrug (2009) the suggested average internal coarse fodder price is stated as 1.30 DKK per FE for organic farms in 2009. It is assumed that this price also applies to grass clover and therefore the accounting price of this crop is fixed as 1.30 DKK per FE multiplied by the net tax factor 1.17. The value of the production increase of grass clover of 755,055 FE becomes 1.15 M DKK.

Transport

The costs associated with this increased transport is calculated as in scenario 1A – cf. Section 4.2.1.

Biogas plant

The economic consequences for the biogas plant are calculated as in scenario 1A. The only difference is that the total welfare economic value of biogas produced now is estimated to be 3.79 M DKK. because the amount of biogas for sale to the local CHP plant has increased from 1,332,719 Nm^3 to 1,798,622 Nm^3 natural gas equivalents. The reason for the increased production is the higher energy content of cattle compared to pig slurry.

10.2.2 Value of emission consequences

The values of the different emission consequences are estimated by following the same calculation principles and assuming the same accounting prices as in scenario 1A – cf. Section 4.2.2.

10.2.3 Public net income – tax distortion loss

In Section 10.1.3 it was calculated that the public sector will loose annual tax income equal to 5.22 M DKK. To this must be added an investment subsidy of total 14.5 M DKK, which means an annual expenditure of 0.89 M DKK. This amount is calculated by annualizing the 14.5 M DKK over a period of 25 years with a social discount rate of 4 pct. In total annual public net income will decrease with 6.11 M DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 1.22 M DKK.

10.3 Financial analysis

In Table 10.7 it is shown how the financial circumstances of the involved economic sectors are affected. It is seen from the table that now all sectors except the state are actually gaining from the production of biogas. Compared to scenario 1A, this result is due to the fact that the higher dry matter content of cattle slurry compared to pig slurry now makes biogas production profitable for the biogas plant. That is, costs remain unchanged while gas production and thereby also income increases.

Table 10.7 Calculation of financial consequences of biogas production from 100 % cattle slurry at a biogas plant with a treatment capacity of 800 tonnes per day - M DKK.

	Consequence per year	Price	Income and expenditures, M
Agriculture			1.72
- barley production	3,677 hkg	100 DKK pr hkg	0.37
- triticale production	3,677 hkg	100 DKK pr hkg	0.37
- grass clover production	755,055 FE	1.30 DKK pr FE	0.98
Biogas plant			0.28
- biogas production for sale	1,798,622 Nm^3 natural	4.4 DKK pr Nm^3	7.91
- electricity production for sale	5,876,770 kWh	0.772 DKK pr kWh	4.54
- investment costs	5.35 M DKK		- 5.35
- construction subsidy	1.07 M DKK		1.07
- labour	2 persons' work	320,000 DKK	- 0.64
- electricity consumption	1,606,000 kWh	0.65 DKK pr kWh	- 1.04
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03
- chemicals	25,000 DKK	25,000 DKK	- 0.03
- service and maintenance	2,345,000 DKK		- 2.35
- transport of slurry and residual	292,000 km	13.00 DKK pr km	- 3.80
Local CHP plant			0.51
- consumption of biogas	1,798,622 Nm^3 natural	4.4 DKK pr Nm^3	- 7.91
- decreased consumption of natural gas	1,798,622 Nm^3 natural	1.782 DKK pr Nm^3	3.21
- biogas based power production	7,913,935 kWh	0.411 DKK pr kWh	3.25
- CO_2 tax exemption	1,798,622 Nm^3 natural	0.351 DKK pr Nm^3	0.63
- exemption from tax on natural gas for heat	1,798,622 Nm^3 natural	0.742 DKK pr Nm^3	1.33
The state			- 6.28
- construction subsidy	1.07 M DKK		- 1.07
- biogas based power production	7,913,935 kWh	0.411 DKK pr kWh	- 3.25
- CO_2 tax exemption	1,798,622 Nm^3 natural	0.351 DKK pr Nm^3	- 0.63
- exemption from tax on natural gas for heat production	1,798,622 Nm^3 natural gas	0.742 DKK pr Nm^3	- 1.33

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

In the following section the financial calculations are explained in more detail.

10.3.1 Agriculture

It is seen from Table 10.7 that the agricultural sector annually gets a profit equal to 1.72 M DKK. The profit is due to increased crop yields when treated cattle slurry is used as fertilizer by organic farmers. The price of 100 DKK per hkg for barley and triticale and of 1.30 DKK per FE for grass clover is based on Videncentret for landbrug (2009).

10.3.2 Biogas plant

The biogas plant is expected to get an annual net income of 0.28 M DKK. The prices used in the calculations are the same prices as in scenario 1A – cf. Section 4.3.2.

10.3.3 Local CHP plant

The financial result for the local CHP plant is equal 0.51 M DKK. The calculations follow the same methodology and assumptions as in scenario 1A – cf. Section 4.3.3.

10.3.4 The State

The state has increasing expenditures because of the construction subsidy to the biogas plant and biogas based power production at the local CHP plant. In addition to this the state loses tax income from fertilizer tax, CO_2 tax and tax on natural gas for heat production. In total net expenditures of the state are increased with 6.28 M DKK.

11 Biogas production from 100 % organic cattle slurry at 500 tonnes per day plant, scenario 3B

Scenario 3B is very similar to scenario 3A, the primary difference being the processing capacity of the biogas plant. In scenario 3B the daily input capacity of the plant is 500 tonnes, which is equivalent to an annual input of 182,500 tonnes. This implies that the plant requires input from 6,784 dairy cows (8,868 LU's). The only other difference between scenarios 3A and 3B is the assumed average distance between the farms supplying the slurry and the biogas production plant; where it is assumed to be 15 km in scenario 3A it is only assumed to be 10 km in scenario 3B.

11.1 Consequence description

All consequences associated with scenario 3B except 1) investment and operating costs, and 2) the costs of transporting the slurry to biogas production (including transport related emissions) are directly proportional to the amount of input used for biogas production and can therefore be assessed by a simple downscaling of the changes estimated for scenario 3A. More specifically, the changes applying to scenario 3B are calculated by multiplying the changes assessed for scenario 3A by 0.625 (i.e. 500 tonnes per day/800 tonnes per day = 0.625). For descriptions of the consequences and the approaches used to quantify these consequences reference is made to the previous chapters.

The consequences in relation to investment and operating costs and the transportation costs of scenario 3B are identical to those of scenario 1B where slurry also constituted the sole input to biogas production. Hence, for more detailed information on these consequences reference is made to Section 5.1.

The consequences of scenario 3B are listed in Table 11.1.

Table 11.1 Calculation of consequences of biogas production from 100 % organic cattle slurry at biogas plant with a treatment capacity of 500 tonnes per day.

	Consequence per year
Economic consequences	
Agriculture – production (increased production following improved plant availability of N in treated slurry)	
- barley production	2,292 hkg
- triticale production	2,292 hkg
- grass clover production	471,907 FE
Transport	
- slurry to biogas plant and residual product to farmers	121,667 km
Biogas plant	
- biogas production for sale (natural gas equivalents)	1,124,139 Nm^3
- electricity production for sale	3,672,981 kWh
- investment costs	53.3 M DKK (total amount)
- labour	1 persons' work
- electricity consumption	1,003,750 kWh
- water consumption	1,000 m^3
- chemicals	25,000 DKK
- service and maintenance	1,708,000 DKK

Emission consequences	Total, tonne	Agriculture, tonne	Biogas, tonne	Transport, tonne
- CO_2 emissions	-3627.33		-3,725.652	98.319
- N_2O emissions	-13.398	-13.483	0.081	0.004
- CH_4 emissions	-161.636	-173.375	11.734	0.005
- C content of soil	-492.75	-492.75		
- particle emissions	0.142		0.130	0.012
- NO_x emissions	9.391		8.659	0.732
- SO_2 emissions	1.223		1.222	0.001
- CO emissions	21.21		21.092	0.118
- NMVOC emissions	-3.409		-3.427	0.018
Taxes and subsidies				
Biogas plant				
- construction subsidy (20 pct.)			10.7 M DKK (total amount)	
CHP plant				
- biogas based power production (subsidy)				- 2.033 M DKK
- CO_2 tax exemption				- 0.394 M DKK
- exemption from tax on natural gas for heat production				- 0.834 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.
Note: Amounts stated in DKK are stated in 2009 prices.

11.2 Welfare economic analysis

In Table 11.2 the consequences, accounting prices and welfare economic value of consequences of biogas production from 100 % cattle slurry at a biogas plant with a treatment capacity of 500 tonnes per day are shown. The approaches used in the calculations are similar to those used in Scenario 1A; hence, for specification of the calculation principles, reference is made to Chapter 4. Here we solely present the results.

It is seen in Table 11.2 Table it is seen that the biogas production results in a welfare economic loss to society of 4.1 M DKK. Of the total loss 3.71 M DKK, - 0.39 M DKK and 0.78 M DKK are due to economic consequences, emission consequences and taxes and subsidies respectively

Table 11.2 Calculatio of welfare economic value of biogas production from 100 % cattle slurry at a biogas plant with a treatment capacity of 500 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 3.71
Agriculture - production			
- barley production	2,292 hkg	100 DKK pr hkg · 1.17	0.27
- triticale production	2,292 hkg	100 DKK pr hkg · 1.17	0.27
- grass clover production	471,907 FE		
Transport			
- slurry to biogas plant and residual product to farmers	121,667 km	15,22 DKK pr km	- 1.85
Biogas plant			
- biogas production for sale	1,124,139 Nm^3	1.8 DKK pr Nm^3 · 1.17	2.37
- electricity production for sale	3,672,981 kWh	0.46 DKK pr kWh · 1.17	1.98
- investment costs	3.28 M DKK.	3.28 M DKK · 1.17	- 3.84
- labour	1 persons' work	320,000 DKK · 1.17	- 0.37

- electricity consumption	1,003,750 kWh	0.46 DKK pr kWh · 1.17	- 0.54
- water consumption	1,000 m^3	25 DKK pr m^3 · 1,17	- 0.03
- chemicals	25,000 DKK	25,000 DKK · 1.17	- 0.03
- service and maintenance	1,708,000 DKK	1,708,000 DKK · 1.17	- 2.0
Emission consequences			0.39
- CO_2 emissions [1]	-3,627.33 +	105 DKK pr tonne · 1.17	0.3
- N_2O emissions	-13.398 tonnes	105 DKK pr tonne · 310 ·	0.51
- CH_4 emissions	-161.636 tonnes	105 DKK pr tonne · 21 ·	0.42
- C content of soil	-492.75 tonmes	105 DKK pr tonne · 3,67·	- 0.22
- particle emissions	0.142 tonnes		
- NO_x emissions	9.391 tonnes	55,000 DKK pr tonne	- 0.52
- SO_2 emissions	1.223 tonnes	85,000 DKK pr tonne	- 0.10
- CO emissions	21.21 tonnes		
- NMVOC emissions	-3.409 tonnes		
Public net income	-3.91 M DKK	- 3.921 M DKK · 0,2	- 0.78
Total			- 4.1

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh · 1.17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 3,627.33 tonnes deducted reduced CO_2 emissions from alternative electricity production 1,198.485 tonnes.

Subsidies and loss of taxes which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 0.78 M DKK to society. This is due to the assumption that government expenditures and loss of tax income need to be financed by tax. Even if the financing problem is ignored production and use of biogas still lead to a welfare economic loss 3.32 M DKK. The total reduction, measured in CO_2 equivalents, in GHG emissions entailed by the scenario is equal to: (3,627.33 + 13.398 *310 + 161.636 *21 – 492.75 *3.67) tonne = 9,367 tonnes. The value of this reduction is equal to 1.15 M DKK. If this value is subtracted from the total welfare economic costs of biogas production, an estimate is obtained of the welfare economic cost that society will have to pay to obtain the climate gas emission reduction. More specifically, it appears that it will cost society a welfare economic loss of 5.25 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case 560 DKK per tonne CO_2.

Financial analysis

In Table 11.3 it is shown how the financial circumstances of the involved economic sectors are affected. It is seen from the table that the agricultural sector, the local CHP plant and the biogas plant are all economic winners while the state is the looser. Of course, as discussed in Section 10.3, this result depends on assumptions about relative prices and about which sectors receive income and bear expenditure burden.

Table 11.3 Calculation of financial consequences of biogas production from 100 % cattle slurry at a biogas plant with a treatment capacity of 500 tonnes per day - M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			1.07 M DKK
- barley production	2,292 hkg	100 DKK pr hkg	0.23 M DKK
- triticale production	2,292 hkg	100 DKK pr hkg	0.23 M DKK
- grass clover production	471,907 FE	1.30 DKK pr FE	0.61 M DKK
Biogas plant			0.33 M DKK
- biogas production for sale	1,124,139 Nm^3 natural gas	4.4 DKK pr Nm^3	4.95 M DKK
- electricity production for sale	3,672,981 kWh	0.772 DKK pr kWh	2.84 M DKK
- investment costs	3.93 M DKK		- 3.93 M DKK
- construction subsidy	0.79 M DKK		0.79 M DKK
- labour	1 persons' work	320,000 DKK	- 0.32 M DKK
- electricity consumption	1,003,750 kWh	0.65 DKK pr kWh	- 0.65 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 DKK	- 0.03 M DKK
- service and maintenance	1,708,000 DKK	1,708,000 DKK	- 1.71 M DKK
- transport of slurry and residual	121,667 km	13.00 DKK pr km	- 1.58 M DKK
Local CHP plant			0.3 M DKK
- consumption of biogas	1,124,139 Nm^3 natural gas	4.4 DKK pr Nm^3	- 4.95 M DKK
- decreased consumption of natural gas	1,124,139 Nm^3 natural gas	1.782 DKK pr Nm^3	2.00 M DKK
- biogas based power production	4,946,210 kWh	0.411 DKK pr kWh	2.03 M DKK
- CO_2 tax exemption	1,124,139 Nm^3 natural gas	0.351 DKK pr Nm^3	0.39 M DKK
- exemption from tax on natural gas for heat	1,124,139 Nm^3 natural gas	0.742 DKK pr Nm^3	0.83 M DKK
The state			- 4.04 M DKK
- construction subsidy	0.79 M DKK		- 0.79 M DKK
- biogas based power production	4,946,210 kWh	0.411 DKK pr kWh	- 2.03 M DKK
- CO_2 tax exemption	1,124,139 Nm^3 natural gas	0.351 DKK pr Nm^3	- 0.39 M DKK
- exemption from tax on natural gas for heat production	1,124,139 Nm^3 natural gas	0.742 DKK pr Nm^3	- 0.83 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

12 Biogas production from 100 % organic cattle slurry at 50 tonnes per day plant, scenario 3C

Scenario 3C is similar to scenarios 3A and 3B in terms of the type of input used for biogas production; hence, slurry from dairy cows constitutes the sole biomass input. The biogas plant is a farm plant with a daily processing capacity of 50 tonnes (18,250 tonnes per year), which is equivalent to the amount of slurry produced by 678 dairy cows (887 LU'S).

As the biogas plant is a farm biogas plants, the assumptions made for scenario 3C regarding the use of the produced biogas are similar to those made in scenario 1C and 2C. Moreover, scenario 3C is similar to the other farm plant scenarios in the sense that no additional transport requirement is associated with the production.

In relation to agriculturally related effects, scenario 3C is similar to scenarios 3A and 3B, only the scale is different due to the smaller treatment capacity of the facility.

In terms of emission changes, changes are induced by the changes in energy production related to the increased production of heat and electricity from biogas and the subsequent displacement of "generic electricity" and oil based heat production.

12.1 Consequence description

The agriculturally related changes induced by biogas production are directly proportional to the amount of input used for biogas production. For these directly input related factors the changes induced by scenario 3C are assessed by a simple downscaling of the changes estimated for scenario 3A and 2B and therefore the relevant values are listed in the table without further specification. The assumptions underlying the assessment of the consequences related the production and use of biogas (incl. emissions consequences) are similar to those made for scenario 1C and 2C; hence, for more detailed information on the calculations reference is made to previous Chapters.

Table 12.1 contains a list of all the consequences associated with scenario 3C.

Table 12.1 Calculation of consequences of biogas production from 100 % organic cattle slurry at farm biogas plant with a treatment capacity of 50 tonnes per day.

Economic consequences				Consequence per year
Agriculture – production (increased production following improved plant availability of N in treated slurry)				
- barley production				229 hkg
- triticale production				229 hkg
- grass clover production				47,191 FE
Biogas plant				
- electricity production for sale (total production)				885,214 kWh
- heat production – displaced gasoil				947,113 MJ = 26,405 litre gasoil
- investment costs				8.2 M DKK (total amount)
- labour				365 hours
- electricity consumption				100,375 kWh
- water consumption				300 m^3
- chemicals				2,500 DKK
- service and maintenance				273,000 DKK
Emission consequences	Total	Agriculture	Biogas	Transport
- CO_2 emissions	-422.479		-422.479	-
- N_2O emissions	-1.341	-1.348	0.007	-
- CH_4 emissions	-14.034	-17.338	3.304	-
- C content of soil	-49.275	-49.275		-
- particle emissions	0.004		0.004	-
- NO_x emissions	1.266		1.266	-
- SO_2 emissions	0.057		0.057	-
- CO emissions	2.319		2.319	-
- NMVOC emissions	-0.034		-0.034	-
Taxes and subsidies				
Biogas plant				
- construction subsidy (20 %)				1.64 M DKK (total amount)
On-site CHP plant				
- reduced demand for gas oil – energy tax				65,458 DKK
- reduced demand for gas oil - CO_2 tax				11,090 DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in DKK are stated in 2009 prices.

Below some of the consequences are explained in more detail.

12.1.1 Economic consequences

Biogas production per tonne of input is slightly different for the farm biogas compared to the joint biogas plants. The reason for this being that the production process is assumed to be mesophile process rather than thermophile, and that the time that the biomass is in the biogas reactor is longer (50 days compared to 20). The key factors used to calculate biogas production per tonne of cattle slurry for the farm biogas plant in scenario 2C are listed in Table 12.2.

A daily biomass input of 50 tonnes is equivalent to an annual biomass input of 18,250 tonnes, and with reference to Table 12.2 where the gas production per tonne of input is seen to be equal to 11.05 Nm^3 natural gas equivalents this implies that the gross annual production of the facility amounts to approximately 201,000 Nm^3 natural gas equivalents. Using that the lower heating value of natural gas is 39.6 MJ per Nm^3 this is equivalent to a gross annual production of approximately 7,960,000 MJ.

Table 12.2 Calculation of biogas production per tonne of cattle slurry at farm biogas plant.

Dry matter (DM) content of cattle slurry	8 %
Kg DM pr tonne cattle slurry	80
VS/DM ratio [1]	0.8
Kg VS pr tonne cattle slurry [1]	64
Nm^3 CH_4 pr kg VS (HRT=50 days) [1]	0.19
Nm^3 CH_4 pr tonne cattle slurry	12.16
CH_4 content of biogas	60 %
Biogas production (Nm^3 pr tonne cattle slurry)	20.3
Heating value CH_4 (lower; MJ pr Nm^3)	35.9
Heating value Natural gas (lower; MJ pr Nm^3)	39.9
Ratio: Natural gas/CH_4	1.1
Production in natural gas equivalents (Nm^3 pr tonne cattle slurry)	11.05

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be decomposed.

In Table 12.3 it is specified how the produced biogas is used. The process heat requirement for scenario 3C is identical to that applying to scenario 1C.

Table 12.3 Specification of the use of biogas production.

Use	Share of gross production (%)	Share in relevant energy equivalents
Gross energy production	100	201,185 Nm^3 Natural gas eq.
Process heat [1]	12.4	991,705 MJ
Electricity for sale [1,2]	40	885,214 kWh
Excess heat production [1, 3]	39.6	3,157,043 MJ

1. All heat and electricity production is assumed to be produced at a on-site CHP facility.
2. Electricity for sale is equal to gross electricity production.
3. Of the excess heat production only 30 % are assumed to be used; the remaining 70 % are assumed to be lost.

In contrast to the joint biogas plant scenarios where the biogas production in excess of what is needed to cover the process heat requirement is sold to a local CHP facility the entire biogas production is assumed to be used on the on-plant CHP for the farm biogas plants. The entire amount of electricity (885,214 kWh) produced at the CHP is sold. In terms of the excess heat production it is assumed that 30 % is put to use, while the remaining 70 % is lost. The 30 % of excess heat production replaces an amount of gasoil equal to 3,157,043 MJ $\cdot$ 0.30 : 35.87 MJ per litre = 20,405 litre gasoil

In Table 12.4 the investment costs for scenario 3C are listed. The investment cost calculations are based on Petersen (2010).Following the approach used in the other scenarios the CHP related costs are based on a cost per MJ of 0.075 DKK. With a gross annual production of 201,185 Nm^3 Natural gas equivalents, which is equivalent to approximately 8,000,000 MJ, estimated CHP investment costs becomes approximately 0.6 M DKK.

Table 12.4 Calculated investment costs for farm biogas plant with a capacity of 50 tonnes per day and 100 % cattle slurry as input - M DKK, factor prices.

CHP	0.6
Biogas plant	7.2
Investment costs (A1)	*7.8*
Projecting/planning costs (5 % of	0.4
Total investment costs	*8.2*

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Service and maintenance costs:

As it appears from Table 12.1 the time required for operating the plant is set to 365 hours. In addition to this 100,375 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 300 m^3 water. Also different chemicals are needed with factor price value equal to 2,500 DKK. Finally annual service and maintenance costs of the biogas plant are set to 3.5 % of A1, which is equal to 273,000 DKK. The operating cost calculations are based on Petersen (2010).

Emission consequences

The more specific energy related emissions changes pertaining to scenario 3C are listed in Table 12.5. The assumptions underlying the calculations are similar to those applied in scenario 1C – see Section 6.1.2.

Table 12.5 Calculatede emissions changes from the changes in energy production caused by the production of biogas from 100 % cattle slurry at a farm biogas plant with a daily input capacity of 50 tonnes - tonne.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	TSP	NO_x	SO_2	CO	NMVOC
Biogas based CHP-production	Total production (7,966,928 MJ)	EF (g pr MJ):	0.0000	0.0016	0.4340	0.0026	0.2020	0.0192	0.3100	0.0100
		Change (tonne):	0.0000	0.0127	3.4576	0.0210	1.6093	0.1530	2.4697	0.0797
Reduced consumption of "generic"-electricity	Net electricity sale from biogas plant	EF (g pr MJ):	124.7222	0.0018	0.0542	0.0042	0.1042	0.0264	0.0389	0.0111
	(2,825,421 MJ)	Change (tonne):	-352.3928	-0.0051	-0.1530	-0.0118	-0.2943	-0.0746	-0.1099	-0.0314
Reduced use of oil for heat production[1]	Displaced oil-based heat prodcution	EF (g pr MJ):	74.0000	0.0006	0.0007	0.0050	0.0520	0.0230	0.0430	0.0150
	(947,113 MJ)	Change (tonne):	-70.0864	-0.0006	-0.0007	-0.0047	-0.0492	-0.0218	-0.0407	-0.0142
	Total net change in emissions (tonne):		-422.4792	0.0071	3.3039	0.0044	1.2658	0.0566	2.3191	0.0341

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity), Nielsen et al. (2010) (biogas) and Danmarks Miljøundersøgelser (2011) (oil).
Note 1: It is assumed that 30 % of the excess heat production is used.

From Table 12.5 it is seen that overall the production of biogas and the associated changes in fuel use in energy production entail net increases in all emissions but CO_2.

12.1.2 Taxes and subsidies

In relation to taxes and subsidies, there is an important difference between scenario 3C and scenarios 1C and 2C. Hence, the 20 % construction subsidy does apply to scenario 3C due to the fact that it is based on organic input and because it satisfies the requirement of min. 50 % manure, which need to be fulfilled for organic biogas plants to be qualified for the subsidy. Being 20 % of investment costs the subsidy amounts to 1.64 M DKK. for scenario 3C.

As 30 % of the excess heat production at the on-site CHP displaces gasoil consumption the State will lose tax income associated with the consumption of gasoil. More specifically, the government will loose income from a gasoil tax of 2.479 DKK per litre gasoil and a CO_2 tax of 0.42 DKK per litre gasoil. The amount of gasoil displaced in scenario 2C is equal to 26,405 litre and consequently the losses in tax income are estimated to 65,458 DKK (gasoil tax) and 11,090 DKK (CO_2 tax).

The total annual loss in tax income incurred by the government is 76,548 DKK.

12.2 Welfare economic analysis

In table 12.6 the welfare economic consequences associated with biogas production according to scenario 3C, their accounting prices, and their resulting welfare economic value are listed. The approaches used in the calculations are similar to those used in scenario 1A; hence, for specification of the calculation principles, reference is made to Chapter 4. Here we solely present the results.

It is seen from the table the total annual welfare economic value of biogas production from 100 % cattle slurry at a biogas plant with a treatment capacity of 50 tonnes per day is equal to - 0.38 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss, economic consequences account for 0.35 M DKK, emissions consequences for - 0.01 M DKK and taxes and subsidies for 0.04 M DKK.

Subsidies and loss of taxes which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 0.04 M DKK to society. This is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases which are the occasion of so-called dead weight losses. If the financing problem is ignored production and use of biogas still lead to a welfare economic loss of 0.34 M DKK.

The total annual reduction in greenhouse gas emissions brought about by the scenario is: (422.479- 1.341 *310 + -14.034 * 21 – 49.275 * 3.67) tonnes = 952.06 tonnes, and the value of this reduction is equal to 0.12 M DKK. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 0.5 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case 525 DKK per tonne CO_2.

Below, the individual entries of the welfare economic account are explained.

Table 12.6 Calculated welfare economic value of biogas production from 100 % cattle slurry at a farm biogas plant with a treatment capacity of 50 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic
Economic consequences			- 0.35
Agriculture - production			
- barley production	229 hkg	100 DKK pr hkg · 1.17	0.03
- triticale production	229 hkg	100 DKK pr hkg · 1.17	0.03
- grass clover production	47,191 FE	1.30 DKK pr FE · 1.17	
Biogas plant			
- electricity production for sale	885,214 kWh	0.46 DKK pr kWh · 1.17	0.48
- heat production – displaced gasoil	947,113 MJ = 26,405 litre	110 DKK pr GJ · 1.17	0.12
- investment costs	0.5 M DKK.	0.5 M DKK · 1.17	- 0.59
- labour	365 hours	200 DKK · 1.17	- 0.09
- electricity consumption	100,375 kWh	0.46 DKK pr kWh · 1.17	- 0.05
- water consumption	300 m^3	25 DKK pr m^3 · 1,17	- 0.01
- chemicals	2,500 dkk	2.500 DKKk · 1.17	- 0.00
- service and maintenance	273,000 DKK	273,000 DKK · 1.17	- 0.27
Emission consequences			0.01
- CO_2 emissions [1]	-422.479 + 352.393	105 DKK pr tonne · 1.17	0.01
- N_2O emissions	-1.341	105 DKK pr tonne · 310 · 1.17	0.05
- CH_4 emissions	-14.034	105 DKK pr tonne · 21 · 1.17	0.04
- C content of soil	-49.275	105 DKK pr tonne · 3,67· 1,17	- 0.02
- particle emissions	0.004		
- NO_x emissions	1.266	55,000 DKK pr tonne	-0.07
- SO_2 emissions	0.057	85,000 DKK pr tonne	-0.00
- CO emissions	2.319		
- NMVOC emissions	-0.034		
Public net income	- 0.18 M DKK	-0.18 M DKK · 0,2	- 0.04
Total			- 0.38

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh · 1,17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 422.479 tonnes deducted reduced CO_2 emissions from alternative electricity production 352.393 tonnes.

12.2.1 Value of economic consequences

Generally accounting prices of economic consequences are determined as for scenario 1A – cf. Section 4.2.1 – and scenario 1C (gasoil) – cf. Section 6.2.1.

12.2.2 Value of emission consequences

With regard to determination of accounting prices for emission consequences refer to Section 4.2.2.

12.2.3 Public net income – tax distortion loss

In Section 12.1.3 it was calculated that the public sector will loose annual tax income equal to 76,548 DKK. To this must be added an investment subsidy of a total of 1.64 M DKK which means an annual expenditure of 0.1 M DKK.

- cf. Section 4.2.3. In total annual public net income will decrease with 0.18 M DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 0.04 M DKK.

12.3 Financial analysis

In Table 12.7 the results of the financial analysis pertaining to scenario 3C are presented. Reference is made to Section 4.3 and 6.3 for more detailed descriptions of the principles applied in the calculations. It is seen from the table that the agricultural sector is the economic winner while the biogas plant and the state both are losers.

Table 12.7 Financial consequences of biogas production from 100 % cattle slurry at a farm biogas plant with a treatment capacity of 50 tonnes per day - M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			0.1 M DKK
- barley production	229 hkg	100 DKK pr hkg	0.02 M DKK
- triticale production	229 hkg	100 DKK pr hkg	0.02 M DKK
- grass clover production	47,191 FE	1.30 DKK pr FE	0.06 M DKK
Biogas plant			- 0.05 M DKK
- electricity production for sale	885,214 kWh	0.772 DKK pr kWh	0.68 M DKK
- heat production – displaced gasoil	947,113 MJ = 26,405 litre	6.845 DKK pr litre	0.18 M DKK
- investment costs	0.61 M DKK		- 0.61 M DKK
- construction subsidy	0.12 M DKK		0.12 M DKK
- labour	365 hours	200 DKK	- 0.07 M DKK
- electricity consumption	100,375 kWh	0.65 DKK pr kWh	- 0.07 M DKK
- water consumption	300 m^3	25 DKK pr m^3	- 0.01 M DKK
- chemicals	2,500 DKK	2,500 DKK	- 0.00 M DKK
- service and maintenance	273,000 DKK	273,000 DKK	- 0.27 M DKK
The state			- 0.2 M DKK
- construction subsidy	120,000 DKK		- 0.12 M DKK
- reduced demand for gas oil – energy tax	65,458 DKK		- 0.07 M DKK
- reduced demand for gas oil - CO_2 tax	11,090 DKK		- 0,01 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

13 Scenario 4A: Biogas production from 50 % organic cattle slurry and 50 % organic grass clover at 800 tonnes per day plant

In scenario 4A biogas production takes place at joint biogas plant with a treatment capacity of 800 tonnes per day. Slurry from organic dairy cattle constitutes 50 % of the input and organic grass clover constitutes the other half of the input. In terms of the grass clover, it is assumed that the growing of grass clover for biogas production displace the production of grass clover for forage (50 %), spring barley for forage (25 %) and winter triticale for forage (25 %). Moreover, it is assumed that the growing of crops takes place on sandy soils (JB 1-3 of the Danish soil classification system) with irrigation.

The annual biomass input requirement of the biogas plant is 292,000 tonnes where slurry and grass clover each accounts for 146,000 tonnes. In terms of the slurry input requirement it is equivalent to the annual slurry production from 5,428 dairy cows (7,095 LU). In relation to grass clover it is assumed that the average production per hectare is 35.04 tonnes. This number assumes a production of 7,300 FE per ha and 1,2 kg DM per FE (Videncentret for landbrug, 2009) and a 25 % DM content of grass clover. Based on this, the input requirement is equivalent to the grass clover production resulting from 4,167 hectares. As was the case in scenario 2, the required change in land use practices is associated with changes in the use of resources in agricultural production, e.g. changes in the use of labour and machinery.

In relation to the assumptions made regarding transport of biomass use of the produced biogas and transport related emissions scenario 4A is similar to scenario 2A where input was also a combination of slurry and plant material.

Turning to the agriculturally related effects relevant for scenario 4A the addition of plant material makes scenario 4A somewhat more complicated than scenario 3A. Despite the fact that the scenario considers biogas production based on inputs from organic agriculture where synthetic fertilizer is not used the scenario indirectly give rise to changes in the application of synthetic fertilizer. More specifically, it is assumed that the grass clover part of the treated biomass, when applied to the field, displace conventional slurry, which currently can be used (in limited amounts) in organic agriculture. The amount of conventional slurry made available by this substitution is subsequently assumed to displace synthetic fertilizer in conventional agricultural production, implying that the scenario indirectly entails a reduction in the application of synthetic fertilizer. In contrast to the pig slurry scenarios where the reduction in synthetic fertilizer application translates into a reduction in N-leaching the opposite is the case in this scenario. Hence, N-leaching increases due to the fact that the rate of N-leaching from grass clover based fertilizer is greater then the rate of N-leaching from synthetic fertilizer. Apart form the effects on N-leaching induced by the substitution of fertilizers N-leaching is also affected by the changes in crop rotation induced by the increased demand for land for grass clover production the reason being that the rate of N-leaching varies across different types of crops.

As in the scenarios based on 100 % cattle slurry there is also an increased yield effect associated with the biogas treatment of slurry in scenario 4A. The increase in yield is brought about by improved plant availability of N in treated compared to untreated slurry. However, the grass clover part of the biomass does not give rise to any yield increases compared to the reference. There is however, a "preceding crop value" effect associated with grass clover and this effect either 1) results in increased yields in the crops that are subsequently grown on the fields where grass clover has been grown, or 2) implies that the level of N-application can be reduced. Apart from these fertilizer, N-leaching and yield effects, scenario 4A also is associated with changes in the emissions of CH_4 and N_2O just as it has implications in relation to the C-content of the soil.

As for the other joint biogas plant scenarios the increased transport requirement associated with the transportation of biomass to and from the biogas plant along with the substitutions induced in the energy production sector also gives rise to emissions changes. In addition to this changes in electricity consumption brought about by changes in the need for irrigation caused by changes in crop rotations also lead to changes in emissions.

13.1 Consequence description

In Table 13.1 the consequences of biogas production from 50 % organic cattle slurry and 50 % organic grass clover at a biogas plant with a treatment capacity of 800 tonnes per day are summarized. The table is divided into three parts covering economic consequences, emissions and taxes and subsidies respectively.

Below the individual consequences are explain in more detail.

Table 13.1 Calculated consequences of biogas production from 50 % organic cattle slurry and 50 % grass clover at a biogas plant with a treatment capacity of 800 tonnes per day.

Economic consequences	Consequence per year
Agriculture – production	
- grass clover production for fodder	- 15,208,333 FE = - 73,000 tonnes
- barley production	- 3,645,833 kg
- triticale production	- 4,687,500 kg
- grass clover production for biogas production	30,416,666 FE = 146,000 tonnes
Agriculture – resource use	
- grass clover seed for fodder production	- 18,064 kg
- barley seed	- 177,083 kg
- triticale seed	- 177,083 kg
- grass clover seed for biogas production	36,128 kg
- labour	- 174 hours
- fuel consumption (diesel)	- 2,252 litre
- electricity consumption (irrigation)	545,182 kWh
- labour (irrigation)	187,500 DKK
- machine costs (incl. irrigation)	324,962 DKK
Agriculture – yield increase	
- barley production - treated slurry	1,839 hkg
- triticale production - treated slurry	1,839 hkg
- grass clover production - treated slurry	377,526 FE
Agriculture – treated grass clover	
- reduced demand for synthetic fertilizer	928,023 kg
Transport	
- slurry and grass clover to biogas plant and – residual product to farmers	438,000 km
- import of grass clover, barley and triticale	60,027 km
Biogas plant	
- biogas production for sale	9,662,045 Nm^3
- electricity production for sale	5,876,770 kWh
- investment costs	101.9 M DKK (total amount)
- labour	2 persons' work
- electricity consumption	1,898,000 kWh
- water consumption	1,000 m^3
- chemicals	25,000 DKK
- service and maintenance	3,325,000 DKK

Emission consequences	Total, tonne	Agriculture, tonne	Transport, tonne	Biogas, tonne
- CO_2 emissions	-22,867.092	238.085	402.458	- 23,507.635
- N_2O emissions	23.164	22.700	0.015	0.449
- CH_4 emissions	-59.791	-64.008	0.021	4.196
- C content of soil	497.675	497.675	0.000	
- particle emissions	0.846	0.003	0.048	0.795
- NO_x emissions	37.969	0.145	2.997	34.827
- SO_2 emissions	7.923	0.052	0.002	7.869
- CO emissions	112.785	0.043	0.483	112.259
- NMVOC emissions	-30.914	0.016	0.075	-31.005
- N-leaching	-59.097	-59.097		

Table 13.1 continued.

Taxes and subsidies	
Biogas plant	
- construction subsidy (20 %)	20.4 M DKK (total amount)
CHP plant	
- biogas based power production (subsidy)	-17.473 M DKK
- CO_2 tax exemption	- 3.391 M DKK
- exemption from tax on natural gas for heat production	- 7.169 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in DKK are stated in 2009 prices.

13.1.1 Economic consequences

Agriculture

The economic consequences for the agricultural sector are shown in Table 13.2. and are first of all connected with the substitution of barley, triticale and grass clover production for feed with the production of grass clover for biogas. This means that resource use will change. The calculations of changes in resource use are based on Videncentret for landbrug (2009), although some adjustments are made. First of all, the same adjustments as described in Section 7.1.1 are made – see Section 7.1.1 for details. The agricultural production is assumed to take place on JB 1-3 soils with irrigation. Hence, the assessment of changes in resource use must also take account for irrigation costs. Irrigation costs are calculated based on Hvid (2008). The costs associated with grass clover production in Videncentret for landbrug (2009) are based on a 2 year crop rotation for grass clover; in this study, however, we assume grass clover to be re-established every 3rd year. Hence, costs for seed and sowing costs are adjusted to reflect this difference.

The more specific changes in resource use are specified in Table 13.2. along with the other effects of biogas production in relation to agriculture.

Table 13.2 Calculated economic consequences of replacing grass clover production for fodder (50 %), spring barley production (25 %) and winter triticale production (25 %) with grass clover production for biogas production on 4,167 hectare land 2,084 ha 1,042 ha.

	Grass clover production	Barley production	Triticale production	Net change
Agriculture – production				
- grass clover production for fodder	- 15,208,333 FE = - 73,000 tonnes			- 15,208,333 FE
- barley production		- 3,645,833 kg		- 3,645,833 kg
- triticale production			- 4,687,500 kg	- 4,687,500 kg
- grass clover production for biogas production	30,416,666 FE = 146,000 tonnes			30,416,666 FE
Agriculture – resource use				
- grass clover seed for fodder production	- 18,064 kg			- 18,064 kg
- barley seed		- 177,083 kg		- 177,083 kg
- triticale seed			- 177,083 kg	- 177,083 kg
- grass clover seed for biogas production	36,128 kg			36,128 kg
- labour	13,399 hours	- 6,460 hours	- 7,111 hours	- 174 hours
- fuel consumption (diesel)	173,117 litre	- 83,462 litre	- 91,870 litre	- 2,252 litre
- electricity consumption (irrigation)	1,362,956 kWh	- 340,739 kWh	- 477,035 kWh	545,182 kWh
- labour (irrigation)	468,900 DKK	- 117,225 DKK	-164,115 DKK	187,500 DKK
- machine costs (incl. irrigation)	4,983,553 DKK	- 2,183,928 DKK	- 2,474,542 DKK	324,962 DKK
Agriculture – yield increase				
- barley - treated slurry		1,839 hkg		
- barley - preceding crop value of grass clover		3,472 hkg		
- triticale - treated slurry			1,839 hkg	
- triticale - preceding crop value grass clover			3,472 hkg	
- grass clover – treated slurry	377,526 FE			
Agriculture – treated grass clover				
- reduced demand for synthetic fertilizer				928,023 kg

Source: Based on information about production and resource use per ha in Videncentret for landbrug (2009).

As no synthetic fertilizer and plant protection are used in organic agriculture the change in land use will have no direct effects on consumption of these inputs. However, as in the scenarios based on 100 % cattle slurry, there is also an increased yield effect associated with the biogas treatment of slurry in scenario 4A. The grass clover part of the biomass does not give rise to any yield increases compared to the reference and therefore, the yield increase is caused by the fact that the ammonium share of N is greater in treated slurry than in untreated slurry – cf. Section 10.1.1.

Based on an N content of cattle slurry of 4.70144 kg per tonne, and a total annual slurry input of 146,000 tonnes the total amount of N in the treated slurry is 686,410 kg. Assuming that the level of N application is 122 kg per ha, this implies that the amount of slurry treated in the biogas plant is equivalent to the amount of slurry needed as fertiliser on 686.410 kg : 122 kg per ha = 5,626.31 hectares and the yield increase is therefore assumed to apply to the agricultural production on 5,626 hectares.

Spring barley and triticale are each assumed to be grown on 25 % of the affected area, i.e. on 1,407 ha. Using that the expected increase in ammonium N brought about by biogas treatment is 10 % of total N, that the level of N application is 122 kg per ha and that the increase in yield for cereal crops is 0.1071428 hkg per kg ammonium N made available the resulting yield increases for triticale and spring barley are: 1,407 ha · 122 kg Amm-N per ha · 0.1 · 0.1071428 hkg per kg Amm-N = 1,839 hkg. Grass clover is assumed to be grown on the remaining 50 % of the area - i.e. 2,813 ha - and with an expected increase in ammonium N of 12.2 kg per ha the total increase in ammonium N is 343,205 kg. Using that grass clover yield is assumed to increase by 11 FE when the availability of ammonium N is increased by 1 kg, the expected increase in the yield of grass clover amounts to 377,526 FE.

While biogas treatment of slurry gives rise to an increased yield due to improved plant availability of N the growing of grass clover is associated with a "preceding crop value". The preceding crop value associated with grass clover arises due to the nitrogen fixating properties of grass clover. Thus, the N-content of the crop residue left in the field represents an important fertilizer value in relation to the crops succeeding grass clover in the crop rotation. More specifically, the preceding crop value of grass clover is assumed to be equivalent to 100 kg N per ha, and this increase in N can either be used to obtain an increased yield in the crops that are subsequently grown on the fields where grass clover has been grown (i.e. the preceding crop value is seen as a way to increase the overall level of N-application) or to reduce the level of "external" N application (i.e. the overall level of N-application is maintained and yields are kept constant, but the demand for N from slurry is reduced). For scenario 4A (and the other 100 % organic cattle slurry scenarios) the preceding crop value effect is accounted for by assuming that it entails a reduction in the demand for slurry, implying that yield is maintained.

As mentioned in the introduction to this chapter, it is assumed that the grass clover part of the treated biomass, when applied to the field as fertilizer, displace conventional pig slurry, which currently can be used (in limited amounts) in organic agriculture. Hence, both the substitution caused by the substitution of pig slurry with treated grass clover and the preceding crop value effect give rise to reductions in the demand for pig slurry. The amount of conventional slurry made available is subsequently assumed to displace synthetic fertilizer in conventional agricultural production implying that the scenario indirectly entails a reduction in the application of synthetic fertilizer.

The reduction in the demand for pig slurry from conventional agriculture is determined by the N-content of the treated grass clover plus the amount of N added to the soil due to the nitrogen fixating properties of grass clover, i.e. the preceding crop value effect. For grass clover the N-content is 32 kg per tonne dry matter. Setting the dry matter content to 25 % this is equivalent to a N-content of 8 kg per tonne grass clover. For scenario 4A, where the total annual input of grass clover is 146,000 tonnes, the total annual N-content of the treated grass clover therefore becomes 1,168,000 kg. As mentioned above, the preceding crop value of grass clover is assumed to be 100 kg N per ha, which for scenario 4A where the grass clover area increases with 2,083 ha amounts to a total of 100 kg N per ha · 2,083 ha : 3 years = 69,444 kg per year. In total, the amount of N which entails a reduction in the demand for pig slurry is 1,168,000 kg + 69,444 kg = 1,237,444 kg. Based on a N-content of pig slurry of 3,931335 kg per tonne the subsequent reduction in the demand for pig slurry from conventional agriculture is 1,237,444 kg : 3.931335 kg per tonne = 314,764 tonnes. The reduction in the application of synthetic fertilizer, which results from the increased amount of slurry available for application within conventional agriculture, is equal to 75 % of the N-content of the slurry, i.e. 0.75 · 1,237,444 kg = 928,083 kg.

Transport

The key factors used to calculate the transport requirement associated with transport to and from the biogas plant in scenario 4A are listed in Table 13.3 where it also is seen that the total transport requirement is 438.000 km. In connection with the calculations of the biomass related transport requirement for the scenarios involving cattle slurry and grass clover it may be noted that the quite high demand for transport is caused by the fact that the lorries used to transport the plant material part of the input cannot drive with return loads, i.e. they drive empty half of the time.

It can be seen that the transport requirement is 146,000 tonnes: 30 tonnes 30 km = 146,000 km for slurry and treated slurry, 146,000 tonnes: 30 tonnes 30 km = 146,000 km for treated grass clover and 146,000 tonnes: 30 tonnes 30 km = 146,000 km for grass clover. Total transport requirement is 438,000 km.

Table 13.3 Annual biomass related transport requirement for scenario 4A.

Slurry to biogas plant (tonnes per year)	146.000
Grass clover to biogas plant (tonnes per year)	146.000
Treated biomass from biogas plant (tonnes per year)	292.000
Distance between farm and biogas plant (km; one way/return)	15/30
Capacity of tank trucks and lorries (tonnes)	30
No. of return trips tank trucks (slurry and treated grass clover)	4.867 (slurry) + 4.867 (treated grass clover)
No. of return trips lorries (grass clover to biogas plant)	4.867
Total no. of km	438.000

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

As was the case for the scenarios involving maize as an input to biogas production changes in land use also entail changes in the transport requirements posed by the scenarios involving grass clover. In this connection it is assumed that the displaced production was used for animal feed. Moreover, it is assumed that Denmark is a net importer of animal feed. Hence, the decrease in the production of forage crops induced by the production of grass clover for biogas is assumed to result in an increase in the import of animal feed. For triticale and spring barley, the decrease in the production of these two crops is assumed to entail an equivalent increase in the import of triticale and spring barley. For grass clover, however, it is not realistic to assume an equivalent increase in the import of grass clover. Hence, the demand for transportation, and the associated increase in transportation costs, that this would entail would be prohibitive. In stead it is assumed that the displaced grass clover production is substituted with the import of an equivalent amount – measured in terms of protein content – of soy meal and barley. It is assumed that the yield per ha for grass clover is 7,300 FU, and based on Videncentret for landbrug (2010b) is calculated that the protein content of this amount of grass clover is equivalent to the protein content of 4,656 kg barley and 2,870 kg soy meal. This implies that for each ha where grass clover production is displaced a total of 7,526 kg alternative animal feed has to be imported. In the present scenario where grass clover production is displaced on 2,083 ha the associated increase in the need for import of animal feed is 15,677 tonnes. The increase in import is assumed to entail an increase in the need for transport; i.e. the imported feed has to be transported from the border to the place of use.

The key factors used to calculate the more specific increase in the demand for transport brought about by the land use changes associated with scenario 4A, are listed in Table 13.4. In the present scenario 4.167 hectares are necessary to produce the required amount of grass clover input to biogas production, and the production displaced is 50 % grass clover for feed (2.083 ha), 25 % triticale for feed (1.042 ha) and 25 % spring barley for feed (1.042 ha). Based on a yield per hectare for triticale and spring barley of 4,5 tonnes per ha and 3,5 tonnes per ha, respectively, this translates into displaced productions of 4.688 tonnes for triticale and 3.646 tonnes for spring barley. For grass clover, the increase in import is 15,677 tonnes as specified in the previous paragraph. Similar to the scenarios involving maize, it is assumed that the average distance to the border is 75 km and that the transport is undertaken by 30 tonnes lorries. Subsequently, the total increase in the need for transport is estimated to be 60,027 km.

Table 13.4 Changed transport requirement related to displaced production in scenario 4A.

Displaced production:	Grass clover	Triticale	Spring barley
Ha where production is displaced:	2,083	1,042	1,042
Yield per hectare	35	4.5	3.5
Displaced production (tonne)	73,000	4,688	3,646
Effect of decreased production:	Increased import	Increased import	Increased import
Import requirement (tonne):	15,677	4,688	3,646
Capacity of lorries (tonne)	30	30	30
Distance to border (km)	75	75	75
Change in transport requirement (km) [1]	39,193	11,719	9,115
Total change in transport requirement (km)			60,027

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. It is assumed that the transport can be arranged in such a way that the lorries drive with some kind of return load – i.e. the calculated transport requirements reflect only need for one-way trips.

Biogas plant

The key factors used to calculate biogas production per tonne of input is listed in Table 13.5. For cattle slurry biogas production per tonne of slurry is identical to the production calculated in relation to scenario 3A. For grass clover the DM content is assumed to be 25 %, and this – combined with the higher VS/DM ratio and higher gas production per kg of VS – result in an around six times higher gas production per tonne of grass clover than per tonne of cattle slurry. With an input consisting of 50 % cattle slurry and 50 % grass clover, the average production per tonne of input for scenario 4A is 37,66 Nm^3 natural gas equivalents.

Table 13.5 Calculated biogas production per tonne of input (50 % cattle slurry and 50 % grass clover at joint biogas plant), scenario 4A.

	Cattle slurry (50 % of input)	Grass clover (50 % of input)
Dry matter (DM) content	8 %	25 %
Kg DM pr tonne	80	250
VS/DM ratio [1]	0.8	0.95
Kg VS pr tonne [1]	64	237.5
Nm^3 CH_4 pr kg VS (HRT=20 days) [1]	0.185	0.3
Nm^3 CH_4 pr tonne	11.84	71.25
CH_4 content of biogas	60 %	60 %
Biogas production (Nm^3 pr tonne)	19.7	118.8
Heating value CH_4 (lower; MJ pr Nm^3)	35.9	35.9
Heating value Natural gas (lower; MJ pr Nm^3)	39.9	39.9
Ratio: Natural gas per CH_4	1.1	1.1
Production in natural gas equivalents (Nm^3 pr tonne)	10.8	64.8
Production in natural gas equivalents (Nm^3 pr tonne)		37.66

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be decomposed.

The annual biomass input is 292,000 tonnes and with a biogas production of 37.66 Nm^3 natural gas equivalents per tonne biomass input this implies that the gross annual production of the facility amounts to 10,997,675 Nm^3 natural gas equivalents. Using that the lower heating value of natural gas is 39.6 MJ per Nm^3 this is equivalent to a gross annual production of 435,507,926 MJ.

Table 13.6 Calculatede biogas production.

	Share of gross production (%)	Share in relevant energy equivalents
Gross energy production	100.0	10,997,675 Nm^3 Natural gas eqv.
Process heat [1]	7.3	31,734,560 MJ
Electricity for sale [1]	4.9	5.876.770 kWh
Biogas for sale	87.9	9,662,045 Nm^3 natural gas eq.

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. Process heat and electricity for sale is assumed to be produced at a on-site CHP facility.

In Table 13.6 it is specified how the produced biogas is used. It can be seen from the table that of a total production of 10,997,675 Nm^3 natural gas equivalents biogas about 88 % of it is sold to a local CHP plant. The remaining 12 % is used on an on-plant CHP, which is used to produce the heat necessary for biogas production. The process heat requirement is identical to that of the other 800 tonnes per day scenarios, and so is the amount of electricity produced in connection with the production of the process heat. The electricity produced at the on-plant CHP is sold.

Investment costs for scenario 4A are presented in Table 13.7, where it is seen that operating the biogas plant includes employment of two skilled workmen. In addition to this 1,898,000 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 1,000 m^3 water. Also different chemicals are needed with factor price value equal to 25,000 DKK. In terms of the annual service and maintenance costs of the biogas plant these are set to 3.5 % of A1, which is equal to 3,325,000 DKK. The investment and operating cost calculations are based on Petersen (2010).

Table 13.7 Calculated investment costs for biogas plant with a capacity of 800 tonnes per day and 50 % cattle slurry and 50 % grass clover as input - M DKK, factor prices.

Buildings, roads, etc.	14.8
Storage facilities for grass clover	25.0
Pre-treatment of grass clover	3.0
Reactors, pipes, etc.	17.8
Gas scrubbers	6.0
CRS (Control, Regulation , Supervision system)	15.2
Pumps etc.	6.3
CHP	3.9
Building site	3.0
Investment costs (A1)	95.0
Gas pipeline	2.1
Projecting/planning costs (5 % of A1)	4.8
Total investment costs	101.9

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

13.1.2 Emission consequences

The total emission consequences stated in Table 13.1 are the result of the resource re-allocations described in Section 13.1.1 and like these they can be related to agriculture, transport and biogas production and use respectively. The emissions consequences for each of these three activities are summarized in Table 13.8. In terms of greenhouse gas emissions it is seen that CO_2 and CH_4 decrease, while N_2O emissions increase. Moreover, the C content of soil is seen to increase thereby adding to the positive climate effect. All other emissions to air except NMVOC increase because of biogas production and increased demand for transport. N-leaching will decrease.

Table 13.8 Calculated emission consequences of biogas production from 50 % organic cattle slurry and 50 % organic grass clover at biogas plant with a treatment capacity of 800 tonnes per day - tonne.

Activities	CO_2	N_2O	CH_4	C content of soil	Particles	NO_x	SO_2	CO	NMVOC	N-leaching
Agriculture – biomass		22.696	- 64.114	497.675						- 59.097
Agriculture – energy	238.085	0.004	0.106		0.003	0.145	0.052	0.043	0.016	
Transport - biomass	353.95	0.013	0.018		0.042	2.636	0.002	0.425	0.066	
Transport – barley, triticale	48.508	0.002	0.003		0.006	0.361	0.000	0.058	0.009	
Biogas production and use	-23,507.635	0.449	4.196		0.795	34.827	7.869	112.259	-31.005	
Total	-22,867.09	23.16	-59.79	497.68	0.85	37.97	7.92	112.79	-30.91	-59.10

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Below the different emission changes are explained in more detail.

Emission consequences related to agriculture

In the present section, the agriculturally related changes in N_2O emissions, CH_4 emissions, C-content of the soil and N-leaching induced by scenario 4A are assessed.

As was the case for the scenarios involving pig slurry and maize as inputs to biogas production, several factors contribute to changes in the N_2O emissions between scenario 4A and the reference. The calculations of changes in N_2O emissions are based on the emissions coefficients specified in Appendix I. The N_2O-N emissions coefficient for untreated slurry is set to 2 % of the total N-content of the slurry just as in scenario 3A. For the grass clover part of the input there are no emissions in the reference situation. For the treated biomass – i.e. slurry as well as grass clover - the N_2O-N emissions coefficient is set to 2 % of the total N-content of the biomass. As the N-content of the slurry is unaffected by the production of biogas there are no change in the N_2O emissions originating from the slurry part of the input between the reference situation and the biogas scenario. However, for the grass clover part of the input N_2O-N emissions increase from zero to 2 % of the N-content. With a total annual grass clover input of 146,000 tonnes and the N-content of grass clover set to 8 kg per tonne the total amount of N in the treated grass clover is 1,168 tonnes. The resulting increase in N_20-N emissions is 23.36 tonnes. Using the conversion factor between N_2O-N and N_2O of 44/28, this translates into an increase in N_2O emissions of 36.70857 tonnes.

As already described the use of grass clover for biogas production results in a reduction in the demand for pig slurry from conventional agriculture and subsequently this results in a reduced demand for synthetic fertiliser within conventional agriculture. This reduced demand for synthetic fertiliser give rise to a reduction in N_2O emissions. With reference to Section 13.1.1 the reduction in the demand for synthetic fertiliser N is 928,083 kg and using that N_2O-N emissions from synthetic fertiliser are 1 % of the N-content of the fertiliser the fertiliser related reduction in N_2O-N emissions is 9.28 tonnes. Using the conversion factor between N_2O-N and N_2O of 44/28 this translates into a decrease in N_2O emissions of 14.5959 tonnes.

Finally, the level of N_2O emissions are also affected by differences between the N-content of the crop residue left on the fields in reference situation (50 % grass clover, 25 % triticale and 25 % spring barley) and the biogas scenario (100 % grass clover). More specifically, it is estimated that annual N_2O emissions will be increased by 0,583379 tonne due to changes in the N-content of crop residues.

In total, N_2O emissions related to agriculture increase by 22.696049 tonnes compared to the reference situation.

For the cattle slurry part of the input biogas treatment reduces CH_4 emissions by 0,95 kg per tonne of slurry (Møller & Olesen, 2011). In the present scenario where the annual input of slurry is 146.000 tonnes the resulting reduction in CH_4 emissions is 138.7 tonnes.

For the grass clover part of the input CH_4 emissions are 0 in the reference situation while they in the biogas scenario are set to 1 % of the gross CH_4 production originating from the plant material (Møller, 2011). The total annual grass clover input of the scenario is 146.000 tonnes and using that the CH_4 production per tonne of grass clover is 71.25 m^3 the gross grass clover based CH_4 production of the scenario amounts to 10,402,500 Nm^3. Consequently, the increase in CH_4 emissions is 104,025 Nm^3, which using that the density of CH_4 is 0,717 kg per Nm^3 is equivalent to an increase of 74.585 tonnes.

With reference to the above the reduction in CH_4 emissions brought about in scenario 4A is greater than the increase. Hence, in total the scenario entail a reduction in CH_4 emissions of 64.1141 tonnes per year.

The C content of the soil is affected in two ways by in scenario 4; hence, while the biogas treatment of slurry lead to a reduction in soil C the changed land use leads to an increase in soil C. The calculations of changes in soil C are based on Coleman & Jenkinson (1996), Sørensen (1987), IPCC (1997) and Olesen (2011). The reduction in soil C resulting from biogas treatment of cattle slurry is estimated to be 33.75 kg C per tonne of dry matter in the slurry. With the dry matter content of slurry set to 8 % and with an annual slurry input of 146,000 tonnes the slurry related reduction in soil C is 146,000 tonnes slurry · 0,08 tonne DM per tonnes slurry 0.03375 tonne C per tonne DM = 394.2 tonnes C.

The change in land use induced by the increased demand for grass clover for biogas production also gives rise to changes in the C content of the soil. More specifically, the increase in soil C induced by the transition to grass clover production in stead of grass clover/triticale/spring barley production is estimated to be 0.21405 tonne per ha. For scenario 4A where 4.167 hectares are used for the production of grass clover for biogas the resulting increase in soil C is 891.875 tonnes.

In total, the C-content of the soil increases by 497.675 tonnes per year.

As described in Section 13.1.1 scenario 4A indirectly entails a reduction in the demand for synthetic fertiliser. Hence, the increase in availability of slurry as fertiliser brought about by the use of treated grass clover as fertiliser subsequently lead to a reduction in the demand for synthetic fertiliser within conventional agricultural production. However, this substitution of synthetic fertiliser with treated grass clover does not result in a reduction in the amount of N-leaching. On the contrary, the substitution is in fact expected to be associated with an increase in the level of N-leaching. More specifically, N-leaching from treated grass clover is assumed to be 6 kg N higher than N-leaching from synthetic fertiliser per 100 kg total N applied. The N-content of grass clover is 32 kg per tonne dry matter. Setting the dry matter content to 25 % this is equivalent to a N-content of 8 kg per tonnes grass clover. With a total annual input of grass clover of 146,000 tonnes the total annual N-content of the treated grass clover therefore becomes 1,168 tonnes. Based on this the increase in N-leaching is 0.06 kg N per kg N 1,168,000 kg : 1,000 = 70.08 tonnes.

In addition to the above mentioned effect the level of N-leaching is also affected by the changes in land use associated with the scenario. More specifically, N-leaching from a crop rotation with 100 % grass clover is set to 28 kg N per ha while N-leaching from a crop rotation with 50 % cereal crops and 50 % grass clover is set to 59 kg N per ha. Hence, the land use changes induced by the scenario actually entail a reduction in N-leaching of 31 kg N per ha. The reduction in N-leaching applies to the 4,167 ha used for producing grass clover for biogas production, implying that the total reduction in N-leaching becomes 129.177 tonnes.

In total, the increase in N-leaching is smaller than the decrease in N-leaching. Thus, in total, scenario 4A is associated with a decrease in N-leaching of 59.097 tonnes.

The replacement of grass clover production for fodder (50 %), spring barley production (25 %) and triticale production (25 %) with grass clover production for biogas production (100 %) gives rise to some minor emission consequences related to use of machines and watering. These consequences are stated in Table 13.9.

Table 13.9 Calculated emission consequences of replacing grass clover production for fodder (50 %), spring barley production (25 %) and triticale production (25 %) with grass clover production for biogas production (100 %) - tonne.

Emission factors	CO_2	N_2O	CH_4	PM	NO_x	SO_2	CO	NMVOC
Diesel g pr. MJ	74	0.003	0.001	0.051	0.654	0.002	0.368	0.066
Electricity g pr. kWh	449	0.0065	0.195	0.015	0.375	0.095	0.14	0.04
Emissions								
Machines								
- 90,572 MJ diesel	-6.702	0.000	0.000	-0.005	-0.059	0.000	-0.033	-0.006
Watering								
+ electricity 545,182 kWh	244.787	0.004	0.106	0.008	0.204	0.052	0.076	0.022
Total	238.085	0.004	0.106	0.003	0.145	0.052	0.043	0.016

Source: Changes in emissions from machines are calculated based on emissions coefficients from Winther (2011). Changes in emissions from electricity use are calculated based on emissions coefficients in Energinet.DK (2010).

Growing grass clover needs less use of machines than growing barley and triticale. As seen in Table 13.2 this entails a decrease in annual consumption of diesel of 2,252 litres. Diesel has a calorific value of 35.87 MJ per litre and therefore, the total change in energy consumption related to machine use can be calculated as 2,252 litres 35.87 MJ per litre = 90,572 MJ as stated in Table 13.9. Emission factors related to diesel are stated in the table as well and on the basis of these and the calculated change in energy consumption the emission changes can be calculated.

Growing grass clover also needs more watering than growing barley and triticale which gives rise to an increase in electricity consumption of 545,182 kWh – cf. Table 13.2. Emission changes are calculated on the basis of this energy consumption increase and the stated emission coefficients for electricity production.

Emissions consequences related to transport

The increase in emissions from transporting biomass between farms and biogas plant – total 438,000 km – and the emission increase caused by increased import of barley and triticale – total 60,027 km – are calculated on the basis of the same assumptions about emission coefficients, calorific value of diesel and diesel consumption per km as in scenario 1A – cf. Section 4.1.2.

Emissions consequences related to biogas production and use

The emission changes related to biogas production and use are calculated on the basis of the same method and assumptions about emission coefficients as for scenario 1A in Section 4.1.2. The results for the 50 % organic cattle slurry and 50 % grass clover scenario are summarized in Table 13.10.

Table 13.10 Calculated emissions changes from the changes in energy production caused by the production of biogas from 50 % organic cattle slurry and 50 % grass clover at a joint biogas plant with a daily input capacity of 800 tonnes – tonnes.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	Particles	NO_x	SO_2	CO	NMVOC
	Total production	EF (g pr MJ)	0.00	0.0016	0.4340	0.0026	0.2020	0.0192	0.3100	0.0100
Biogas based CHP-production	(435,507,926 MJ)	Change (tonne):	0	0.6968	189.0104	1.1454	87.9726	8.3618	135.0075	4.3551
Reduced production of electric-	Net electricity sale from	EF (g pr MJ)	124.7222	0.0018	0.0542	0.0042	0.1042	0.0264	0.0389	0.0111
ity with coal as fuel	biogas plant (14,323,573 MJ)	Change (tonne):	-1,786.468	-0.026	-0.776	-0.060	-1.492	-0.378	-0.557	-0.159
Reduced use of natural gas at	Biogas sold to local CHP	EF (g pr MJ)	56.77	0.0006	0.48	0.00	0.14	0.00	0.06	0.09
local CHP	(382,626,993 MJ)	Change (tonne):	-21,721.1667	-0.2219	-184.0388	-0.2908	-51.6533	-0.1148	-22.1918	-35.2008
Total net change in emissions			-23,507.6346	0.4490	4.1958	0.7949	34.8273	7.8690	112.2586	-31.0048

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity) and Nielsen et al. (2010) (biogas and natural gas).

It is seen from Table 13.10 that CO_2 and NMVOC emissions will decrease while all other emissions increase.

13.1.3 Taxes and subsidies

Biogas production is subsidized directly with a subsidy of 20 % of the total investment cost of 101.9 M DKK. This means a governmental expenditure of 20.4 M DKK.

Moreover use of biogas at the local CHP plant is also subsidized in different ways which depends on the amount of power produced and amount of biogas replaced – see Section 3.1. The amount of biogas produced which replaces natural gas at the local CHP is equal to 9,662,045 Nm^3. It has a calorific value of 382,616,993 MJ. Assuming that the local CHP has an efficiency of power production of 40 % the annual electricity production can be calculated as 382,616,993 MJ · 0.40 : 3.6 kWh per MJ = 42,512,999 kWh.

Biogas based power production is subsidized with 0.411 DKK per kWh. So the production of 42,512,999 kWh increases government annual expenditures with 17.473 M DKK. In addition to this the local CHP plant receives tax exemption from both CO_2 tax and from tax on natural gas replaced for heat production. The tax rates are equal to 0.351 DKK and 0.742 DKK per Nm^3 of natural gas replaced at the CHP plant respectively – cf. Section 3.1. So, the total value of tax exemption can be calculated as 9,662,045 Nm^3 (0.351 + 0.742) DKK per Nm^3 = 10.561 M DKK. This amount of money means a loss of income to the government.

In total the government annual net expenditures are increased with 28.03 M DKK to which is added the one-off construction subsidy of 20.4 M DKK. This amount is important for the welfare economic calculations, because it represents a so-called tax distortion loss. Of course, the subsidies and tax exemptions are also important for the financial calculations which inter alia show how the economic situation of biogas plant and local CHP plant is affected by the biogas production and use.

13.1.4 Welfare economic analysis

In Table 13.11 are shown the consequences, accounting prices and welfare economic value of consequences of biogas production based on 50 % organic cattle slurry and 50 % organic grass clover at a biogas plant with a treatment capacity of 800 tonnes per day. It is seen from the table that the total annual welfare economic value of biogas production is equal to -30.41 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss 26.22 M DKK, -1.67 M DKK and 5.86 M DKK are due to economic consequences, emission consequences and taxes and subsidies respectively. Especially loss of grass clover, barley and triticale production, fertilizer value of treated grass clover, transport, value of biogas and investment costs are important for the total result.

Table 13.11 Calculated welfare economic value of biogas production from 50 % organic cattle slurry and 50 % organic grass clover at a biogas plant with a treatment capacity of 800 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 26.22 M DKK
Agriculture – production			
- grass clover production for fodder	-15,208,333 FE = - 73,000 tonnes	1.30 DKK pr FE·1.17	- 23.13 M DKK
- barley production	- 3,645,833 kg	1.5 DKK pr kg·1.17	- 6.40 M DKK
- triticale production	- 4,687,500 kg	1.6 DKK pr kg·1.17	- 8.78 M DKK
- grass clover production for biogas production	30,416,666 FE = 146,000 tonnes		
Agriculture – resource use			
- grass clover seed for fodder production	- 18,064 kg	40 DKK pr kg·1.17	0.85 M DKK
- barley seed	- 177,083 kg	3.6 DKK pr kg·1.17	0.75 M DKK
- triticale seed	- 177,083 kg	3.8 DKK pr kg·1.17	0.79 M DKK
- grass clover seed for biogas production	36,128 kg	40 DKK pr kg·1.17	- 1.69 M DKK
- labour	- 174 hours	150 DKK pr hour·1.17	0.03 M DKK
- fuel consumption (diesel)	- 2,252 litre	3.82 DKK pr liter·1.17	0.01 M DKK
- electricity consumption (watering)	545,182 kWh	0.46 DKK pr kWh · 1.17	-0.29 M DKK
- labour (irrigation)	187,500 DKK	187,500 DKK·1.17	- 0.22 M DKK
- machine costs (incl. irrigation)	324,962 DKK	324,962 DKK·1.17	- 0.38 M DKK
Agriculture - yield increase			
- barley - treated slurry	1,839 hkg	1.5 DKK pr kg·1.17	0.32 M DKK
- triticale - treated slurry	1,839 hkg	1.6 DKK pr kg·1.17	0.34 M DKK
- grass clover production - treated slurry	377,526 FE	1.30 DKK pr FE·1.17	0.57 M DKK
Agriculture – treated grass clover			
- reduced demand for synthetic fertilizer	928,023 kg	7,500 DKK pr tonne · 1,17	8.14 M DKK
Transport			
- slurry and grass clover to biogas plant and residual product to farmers	438,000 km	15,22 DKK pr km	- 6.67 M DKK
- import of grass clover, barley and triticale	60,027 km	15,22 DKK pr km	- 0.91 M DKK
Biogas plant			
- biogas production for sale	9,662,045 Nm^3	1.8 DKK pr Nm^3 · 1.17	20.35 M DKK
- electricity production for sale	5,876,770 kWh	0.46 DKK pr kWh · 1.17	3.16 M DKK
- investment costs	101.9 M DKK (total amount)	6.27 M DKK · 1.17	- 7.34 M DKK
- labour	2 persons' work	320,000 DKK · 1.17	- 0.75 M DKK
- electricity consumption	1,898,000 kWh	0.46 DKK pr kWh · 1.17	- 1.02 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3 · 1,17	- 0.03 M DKK

Continued			
- chemicals	25,000 DKK	25,000 DKK · 1.17	- 0.03 M DKK
- service and maintenance	3,325,000 DKK	3,325,000 DKK · 1.17	- 3.89 M DKK
Emission consequences (ton)			1.67 M DKK
- CO_2 emissions [1]	-22,867.092 + 1,917.576	105 DKK pr tonne · 1.17	2.57 M DKK
- N_2O emissions	23.164	105 DKK pr tonne · 310 · 1.17	-0.88 M DKK
- CH_4 emissions	-59.791	105 DKK pr tonne · 21 · 1.17	0.15 M DKK
- C content of soil	497.675	105 DKK pr tonne · 3,67· 1,17	0.22 M DKK
- particle emissions	0.846		
- NO_x emissions	37.969	55,000 DKK pr tonne	-2.09 M DKK
- SO_2 emissions	7.923	85,000 DKK pr tonne	-0.67 M DKK
- CO emissions	112.785		
- NMVOC emissions	-30.914		
- N-leaching	-59.097	40,000 DKK pr tonne	2.36 M DKK
Public net income	- 29.29 M DKK	- 29.29 M DKK · 0,2	- 5.86 M DKK
Total			- 30.41 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh · 1,17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 22,867.092 tonnes deducted reduced CO_2 emissions from alternative electricity production 1,917.576 tonnes.

Subsidies and loss of taxes which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 5.86 M DKK to society. As mentioned earlier this is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases which are the occasion of so-called dead weight losses. However, other financing possibilities which do not lead to dead weight losses are possible, but even if the financing problem is ignored production and use of biogas still lead to a welfare economic loss 24.55 M DKK.

The total annual reduction in greenhouse gas emissions entailed by the scenario is: (22,867.09 - 23.164 $\cdot$ 310 + 59.791 $\cdot$ 21 + 497.675 $\cdot$ 3.67) tonne = 18,768 tonnes CO_2 equivalents, and the value of this reduction is equal to 2.31 M DKK. As it is seen in the table by far the largest share of this value can be attributed to biogas being regarded as a CO_2 neutral fuel. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 32.72 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case as high as 1,743 DKK per tonne CO_2 equivalent.

Compared to scenario 3A, the welfare economic loss induced by scenario 4A is actually worse. Hence, the value of the increased production of biogas brought about by the significantly higher gas production per tonne of input is not sufficient to compensate for the quite high costs associated with the loss of agricultural production production costs and increased need of transport.

Below, the individual entries of the welfare economic account are explained in detail.

13.1.5 Value of economic consequences

The basis for estimation of accounting prices in welfare economic analysis is explained in Section 4.2.1. Therefore, only new prices compared to scenario 1A are explained below.

Agriculture

Grass clover is not a commercial crop, but in Videncentret for landbrug (2009) an internal price of 1.30 DKK per FE for organic farmers is estimated. This price is increased with the net tax factor to valuate the loss of 15,208,333 FE grass clover production for fodder. Market prices of barley as well as triticale are also stated in Videncentret for landbrug (2009) as 150 DKK and 160 DKK per hkg respectively. These prices are multiplied with the net tax factor to get the accounting prices of barley and triticale which are used to valuate the loss of barley and triticale production of 3,645,833 kg and 4,687,500 kg respectively. Increased yields of the three crops mentioned are valuated with the same prices as the losses. The accounting price for electricity consumption for watering is equal to price for electricity sold by the biogas plant – se Section 4.2.1.

Transport

The costs associated with this increased transport is calculated as in scenario 1A – cf. Section 4.2.1.

Biogas plant

The welfare economic value of biogas sold to a local CHP and the welfare economic costs of resource use are calculated as in scenario 1A - cf. Section 4.2.1.

13.1.6 Value of emission consequences

The value of emission consequences is calculated with the same welfare economic accounting prices as in scenario 1A - cf. Section 4.2.2

13.1.7 Public net income – tax distortion loss

In Section 13.1.3 it was calculated that the public sector will loose annual tax income equal to 28.03 M DKK. To this must be added an investment subsidy of total 20.4 M DKK which means an annual expenditure of 1.26 M DKK. - cf. Section 4.2.3. In total annual public net income will decrease with 29.29 M DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 5.86 M DKK.

13.2 Financial analysis

In Table 13.12 it is shown how the financial circumstances of the involved economic sectors are affected. It is seen from the table that the agricultural sector and the local CHP plant are economic winners while the biogas plant and the state both are losers. Of course, this result depends on assumptions about relative prices and about which sectors receive income and bear expenditure burden.

Thus, it is assumed that the biogas plant pays a price for organic grass clover equal to its internal price per FE. This is the main reason why the agricultural sector gets a profit from changing land use with a view to deliver grass clover for biogas production. Of course changing land use increases resource consumption and import of barley and triticale, but these costs correspond to the value of increased yields and saved synthetic fertilizer when treated slurry and grass clover displaces pig slurry as fertilizer.

Table 13.12 Calculated financial consequences of biogas production from 50 % organic cattle slurry and 50 % organic grass clover at a biogas plant with a treatment capacity of 800 tonnes per day - M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			13.91 M DKK
Production			
- grass clover for fodder	- 15,208,333 FE	1.30 DKK pr FE	-19.77 M DKK
- barley	- 3,645,833 kg	1.5 DKK pr kg	-5.47 M DKK
- triticale	- 4,687,500 kg	1.6 DKK pr kg	-7.50 M DKK
- grass clover for biogas production	30,416,666 FE	1.30 DKK pr FE	39.54 M DKK
Resource use			
- grass clover seed for fodder production	- 18,064 kg	40 DKK pr kg	0.72 M DKK
- barley seed	- 177,083 kg	3.6 DKK pr kg	0.64 M DKK
- triticale seed	- 177,083 kg	3.8 DKK pr kg	0.67 M DKK
- grass clover seed for biogas production	36,128 kg	40 d DKK pr kg	-1.44 M DKK
- labour	- 174 hours	150 DKK pr hour	0.03 M DKK
- fuel consumption (diesel)	- 2,252 litre	4.3 DKK pr litre	0.01 M DKK
- electricity consumption (watering)	545,182 kWh	0.45 DKK pr kWh	-0.25 M DKK
- labour (irrigation)	187,500 DKK		-0.19 M DKK
- machine costs (incl. irrigation)	324,962 DKK		-0.32 M DKK
- import grass clover, barley, triticale – transport	60,027 km	13.00 DKK pr km	-0.78 M DKK
Agriculture - yield increase			
- barley - treated slurry	1,839 hkg	1.5 DKK pr kg	0.28 M DKK
- triticale - treated slurry	1,839 hkg	1.6 DKK pr kg	0.29 M DKK
- grass clover production - treated slurry	377,526 FE	1.30 DKK pr FE	0.49 M DKK
Fertilizer effect of treated grass clover			
- demand for synthetic fertilizer	- 928 tonnes	7,500 DKK pr tonne	6.96 M DKK
Biogas plant			-9.46 M DKK
- biogas production for sale	9,662,045 Nm^3 natural gas	4.4 DKK pr Nm^3	42.51 M DKK
- electricity production for sale	5,876,770 kWh	0.772 DKK pr kWh	4.54 M DKK
- investment costs	7.52 M DKK		- 7.52 M DKK
- construction subsidy	1.50 M DKK		1.50 M DKK
- labour	2 persons' work	320,000 DKK	- 0.64 M DKK
- grass clover consumption	30,416,666 FE	1.30 DKK pr FE	-39.54 M DKK
- electricity consumption	1,898,000 kWh	0.65 DKK pr kWh	- 1.23 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 DKK	- 0.03 M DKK
- service and maintenance	3,325,000 DKK	3,325,000 DKK	- 3.33 M DKK
- transport of slurry and residual	438,000 km	13.00 DKK pr km	-5.69 M DKK
Local CHP plant			2.74 M DKK
- consumption of biogas	9,662,045 Nm^3 natural gas	4.4 DKK pr Nm^3	-42.51 M DKK
- decreased consumption of natural gas	9,662,045 Nm^3 natural gas	1.782 DKK pr Nm^3	17.22 M DKK
- biogas based power production	42,512,999 kWh	0.411 DKK pr kWh	17.47 M DKK
- CO_2 tax exemption	9,662,045 Nm^3 natural gas	0.351 DKK pr Nm^3	3.39 M DKK
- exemption from tax on natural gas for heat	9,662,045 Nm^3 natural gas	0.742 DKK pr Nm^3	7.17 M DKK
The state			-29.53 M DKK
- construction subsidy	1.50 M DKK		- 1.50 M DKK
- biogas based power production	42,512,999 kWh	0.411 DKK pr kWh	- 17.47 M DKK
- CO_2 tax exemption	6,512,573 Nm^3 natural gas	0.351 DKK pr Nm^3	- 3.39 M DKK
- exemption from tax on natural gas for heat	6,512,573 Nm^3 natural gas	0.742 DKK pr Nm^3	- 7.17 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

The biogas plant has a deficit because it has to pay the assumed internal price for grass clover. Perhaps it is possible to agree with suppliers about a lower price, as these gets a profit, but even if the agricultural sector is willing to sell without profit the biogas plant will still have a deficit.

If the agricultural sector and the local CHP plant pay some of the transport costs, the agricultural sector charge a price lower than the internal price for grass clover used for biogas production and the local CHP plant pays a higher price for biogas, e.g. the break-even price between natural gas and biogas for CHP production, it might be possible to cover the economic loss of the biogas plant. However, in any case the state will lose tax income and have increased expenditures for subsidies and therefore, the production and use of biogas will inflict financial loses on at least one of the involved economic sectors.

Of course the state can choose to accept its financial loses because of the large reduction in climate gas emissions which is the most important result of biogas production and use. However, as the welfare economic analysis has shown the value to society of these emission reductions does not appear to be big enough to justify the welfare economic costs of biogas production.

In the following section the financial calculations are explained in more detail.

13.2.1 Agriculture

It is seen from Table 13.12 that the agricultural sector annually gets a profit equal to 13.91 M DKK. The profit is due to higher net income from grass clover production than for barley and triticale production, increased yields when slurry is replaced by residual matter from the biogas production as fertilizer and reduced consumption of synthetic fertilizer because pig slurry is made available when treated grass clover and slurry are used as fertilizer. The price of grass clover of 1.30 DKK per FE is a suggested internal price for coarse fodder, because grass clover for fodder is not a traded crop - cf. Videncentret for landbrug (2009). All other prices and amounts in DKK are also based on Videncentret for landbrug (2009).

13.2.2 Biogas plant

The biogas plant is expected to get an annual net deficit of 9.46 M DKK. The prices used in the calculations are factor prices including not refunded taxes which were the basis for determination of accounting prices in the welfare economic analysis – cf. Section 4.2.1. The financial result for the biogas plant is based on three important assumptions that have been discussed above.

First the biogas plant pays the internal price for grass clover. Alternatively it could have been assumed that grass clover for biogas production is traded to a lower price. This is a possibility because to the given prices the agricultural sector will earn a profit by substituting barley and triticale production with grass clover production and use treated slurry and grass clover as fertilizer.

Second the biogas plant pays for transport of slurry and grass clover from farmers to biogas plant and residual matter from the biogas plant to farmers. Alternatively it could have been assumed that transport is totally or partly paid by farmers because they earn a profit.

With regard to the assumptions about electricity prices and annual investment costs see Section 4.3.2 for further explanation.

13.2.3 Local CHP plant

Apart from increasing expenses due to the purchase of biogas and decreased expenses for buying natural gas the financial circumstances of the local CHP plant are also affected by the subsidy to biogas based power production and exemptions from CO_2 tax and tax on natural gas for heat production. Based on the same assumptions about subsidy to biogas based power production and tax exemption from CO_2 tax and biogas used for heat production as stated in Section 4.1.3 the local CHP plant earns an annual profit of 2.74 M DKK.

13.2.4 The State

The state has increasing expenditures because of the construction subsidy to the biogas plant and biogas based power production at the local CHP plant. In addition to this the state loses tax income from CO_2 tax and tax on natural gas for heat production. In total net expenditures of the state are increased with 29.53 M DKK.

14 Biogas production from 50 % organic cattle slurry and 50 % organic grass clover at 500 tonnes per day plant, scenario 4B

Apart from the processing capacity of the biogas plant, and the assumed distance between the biogas plant and the input supplying farms, scenario scenario 4B is identical to scenario A. The daily input capacity of the considered plant is 500 tonnes, which is equivalent to an annual input of 182.500 tonnes. As slurry accounts for 50 % of the input the annual slurry input requirement is 91.250 tonnes, which is equivalent to the amount of slurry produced by 3.392 dairy cows (4.434 LU's). For grass clover, the annual input requirement is also 91.250 tonnes, which is equivalent to the amount of grass clover produced on 2.604 hectares. In terms of the assumed average distance between the farms supplying the slurry and the biogas production plant, it is assumed that it is 10 km, similar to what has been assumed for the other 500 tonnes per day plants.

14.1 Consequence description

All consequences associated with scenario 4B except 1) investment and operating costs, and 2) the costs of transporting input to biogas production (including transport related emissions) are directly proportional to the amount of input used for biogas production and can therefore be assessed by a simple downscaling of the changes estimated for scenario 4A. More specifically, the changes applying to scenario 4B are calculated by multiplying the changes assessed for scenario 4A by 0,625 (i.e. 500 tonnes per day/800 tonnes per day = 0,625).

The consequences of scenario 4B are listed in Table 14.1. For the consequences which are assessed by simple downscaling, the relevant values for scenario 4B are simply listed in the table; for descriptions of the consequences and the approaches used to quantify them reference is made to the previous chapters. The transport related consequences and the investment and operating costs applying to scenario 4B are assessed in the following sections.

Table 14.1 Calculated consequences of biogas production from 50 % cattle slurry and 25 % grass clover at biogas plant with a treatment capacity of 500 tonnes per day.

Economic consequences	Consequence per year
Agriculture – production	
- grass clover production for fodder	- 9,505,208 FE = - 45,625 tonnes
- barley production	- 2,278,646 kg
- triticale production	- 2,929,688 kg
- grass clover production for biogas production	19,010,416 FE = 91,250 tonnes
Agriculture – resource use	
- grass clover seed for fodder production	- 11,290 kg
- barley seed	- 110,667 kg
- triticale seed	- 110,667 kg
- grass clover seed for biogas production	22,580 kg
- labour	-109 hours
- fuel consumption (diesel)	-1,407 litre
- electricity consumption (watering)	340,739 kWh
- labour (irrigation)	117,188 DKK
- machine costs (incl. irrigation)	203,101 DKK
Agriculture - yield increase	
- barley production - treated slurry	1,149 hkg
- triticale production - treated slurry	1,149 hkg
- grass clover production - treated slurry	235,954 FE
Agriculture – treated grass clover	
- reduced demand for synthetic fertilizer	580,014 kg
Transport	
- slurry and grass clover to biogas plant and – residual product to farmers	182,500 km
- import of grass clover, barley and triticale	37,517 km
Biogas plant	
- biogas production for sale	6,038,778 Nm^3
- electricity production for sale	3,672,981 kWh
- investment costs	73.3 M DKK (total amount)
- labour	1persons' work
- electricity consumption	1,186,250 kWh
- water consumption	1,000 m^3
- chemicals	25,000 DKK
- service and maintenance	2,373,000 DKK

Emission consequences (tonne)	Total	Agriculture	Biogas	Transport – biomass for biogas	Transport – displaced production
- CO_2 emissions	-14,365.67	148.803	-14,692.272	147.479	30.318
- N_2O emissions	14.48	14.188	0.281	0.005	0.001
- CH_4 emissions	-37.37	-40.005	2.623	0.008	0.002
- C content of soil	311.05	311.047			
- particle emissions	0.52	0.002	0.497	0.018	0.004
- NO_x emissions	23.18	0.091	21.767	1.098	0.226
- SO_2 emissions	4.95	0.033	4.918	0.001	0.000
- CO emissions	70.40	0.027	70.162	0.177	0.036
- NMVOC emissions	-19.33	0.010	-19.378	0.028	0.006
- N-leaching	-36.94	-36.936			

Table14.1 continued.

Taxes and subsidies	
Biogas plant	
- construction subsidy (20 %)	14.7 M DKK (total amount)
CHP plant	
- biogas based power production (subsidy)	- 10.92 M DKK
- CO_2 tax exemption	- 2.12 M DKK
- exemption from tax on natural gas for heat production	- 4.48 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.
Note: Amounts stated in DKK are stated in 2009 prices.

Transport

As mentioned in the beginning of the chapter, the distance between the farms supplying the input and the biogas plant are assumed to be 10 km in scenario 4B. As in scenario 4A tank trucks with a capacity of 30 tonnes are used to transport the untreated slurry and the treated biomass while lorries are used to transport the untreated grass clover. With an annual slurry input of 0.5*182,500 tonnes = 91,250 tonnes and an equivalent annual grass clover input the total annual transport requirement is: (91,250 tonnes : 30 tonnes * 20 km) + 2 * (91,250 tonnes : 30 * 20 km) = 182,500 km.

The transport related emissions consequences of scenario 4B are assessed using the same emissions coefficients as in the previous scenarios, and the resulting emissions changes are listed in Table 14.1.

Investment and operating costs

The estimated investment costs for scenario 4B are listed in Table 14.2 where it is seen that total investment costs amount to 73.3 M DKK. The investment cost calculations are based on Petersen (2010).

Table 14.2 Calculated investment costs for biogas plant with a capacity of 500 tonnes per day and 50 % cattle slurry and 50 % grass clover as input - M DKK, factor prices.

Buildings, roads, etc.	11.5
Storage facilities for grass clover	17.0
Pre-treatment of grass clover	2.0
Reactors, pipes, etc.	11.1
Gas scrubbers	4.7
CRS (Control, Regulation , Supervision system)	11.8
Pumps etc.	4.9
CHP	2.5
Building site	2.3
Investment costs (A1)	67.8
Gas pipeline	2.1
Projecting/planning costs (5 % of A1)	3.4
Total investment costs	73.3

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

In terms of operating costs it appears from Table 14.1 that operating the biogas plant is assumed to require the employment of 1 skilled workman. In addition to this 1,186,250 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be

1,000 m^3 water. Also different chemicals are needed with factor price value equal to 25,000 DKK. Finally annual service and maintenance costs of the biogas plant are set to 3.5 % of A1, which is equal to 2,373,000 DKK. The operating cost calculations are based on Petersen (2010).

14.2 Wefare economic analysis

In Table 14.3 the welfare economic consequences associated with biogas production according to scenario 4B, their accounting prices, and their resulting welfare economic value are listed. The approaches used in the calculations are similar to those used in scenario 1A and 4A; hence, for specification of the calculation principles, reference is made to chapters 4 and 13. Here we solely present the results. It is seen from the table the total annual welfare economic value of biogas production is equal to – 18.54 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss, economic consequences account for 15.95 M DKK, emissions consequences for - 1.09 M DKK and taxes and subsidies for 3.68 M DKK.

Table 14.3 Calculated welfare economic value of biogas production from 50 % organic cattle slurry and 50 % organic grass clover at a biogas plant with a treatment capacity of 500 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 15.95 M DKK
Agriculture – production			
- grass clover production for fodder	- 9,505,208 FE = - 45,625 tonnes	1.30 DKK pr FE·1.17	- 14.46 M DKK
- barley production	- 2,278,646 kg	1.5 DKK pr kg·1.17	- 4.0 M DKK
- triticale production	- 2,929,688 kg	1.6 DKK pr kg·1.17	- 5.48 M DKK
- grass clover production for biogas production	19,010,416 FE = 91,250 tonnes		
Agriculture – resource use			
- grass clover seed for fodder production	- 11,290 kg	40 DKK pr kg·1.17	0.53 M DKK
- barley seed	- 110,667 kg	3.6 DKK pr kg·1.17	0.47 M DKK
- triticale seed	- 110,667 kg	3.8 DKK pr kg·1.17	0.49 M DKK
- grass clover seed for biogas production	22,580 kg	40 DKK pr kg·1.17	- 1.06 M DKK
- labour	-109 hours	150 DKK pr hour·1.17	0.02 M DKK
- fuel consumption (diesel)	-1,407 litre	3.82 DKK pr liter·1.17	0.01 M DKK
- electricity consumption (watering)	340,739 kWh	0.46 DKK pr kWh · 1.17	- 0.18 M DKK
- machine services and labour watering	117,188 DKK	117,188 DKK·1.17	- 0.14 M DKK
- maintenance of machines (incl. watering)	203,101 DKK	203,101 DKK·1.17	- 0.24 M DKK
Agriculture - yield increase			
- barley - treated slurry	1,149 hkg	1.5 DKK pr kg·1.17	0.2 M DKK
- triticale - treated slurry	1,149 hkg	1.6 DKK pr kg·1.17	0.22 M DKK
- grass clover production - treated slurry	235,954 FE	1.30 DKK pr FE·1.17	0.36 M DKK
Agriculture – treated grass clover			
- reduced demand for synthetic fertilizer	580,014 kg	7,500 DKK pr tonne · 1,17	5.09 M DKK
Transport			
- slurry and grass clover to biogas plant and residual product to farmers	182,500 km	15,22 DKK pr km	- 2.78 M DKK
- import of grass clover, barley and triticale	37,517 km	15,22 DKK pr km	- 0.57 M DKK
Biogas plant			
- biogas production for sale	6,038,778 Nm^3	1.8 DKK pr Nm^3 · 1.17	12.72 M DKK
- electricity production for sale	3,672,981 kWh	0.46 DKK pr kWh · 1.17	1.98 M DKK
- investment costs	4.51 M DKK	4.51 M DKK · 1.17	- 5.28 M DKK
- labour	1 persons' work	320,000 DKK · 1.17	- 0.37 M DKK
- electricity consumption	1,186,250 kWh	0.46 DKK pr kWh · 1.17	- 0.64 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3 · 1,17	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 DKK · 1.17	- 0.03 M DKK

Continued			
- service and maintenance	2,373,000 DKK	2,373,000 DKK · 1.17	- 2.78 M DKK
Emission consequences (tonne)			1.09 M DKK
- CO_2 emissions [1]	-14,365.67 + 1,116.542	105 DKK pr tonne · 1.17	1.63 M DKK
- N_2O emissions	14.48	105 DKK pr tonne · 310 · 1.17	-0.55 M DKK
- CH_4 emissions	-37.37	105 DKK pr tonne · 21 · 1.17	0.10 M DKK
- C content of soil	311.05	105 DKK pr tonne · 3,67· 1,17	0.14 M DKK
- particle emissions	0.52		
- NO_x emissions	23.18	55,000 DKK pr tonne	-1.27 M DKK
- SO_2 emissions	4.95	85,000 DKK pr tonne	-0.42 M DKK
- CO emissions	70.40		
- NMVOC emissions	-19.33		
- N-leaching	-36.94	40,000 DKK pr tonne	1.48 M DKK
Public net income	- 18.42M DKK	- 18.42 M DKK · 0,2	- 3.68 M DKK
Total			- 18.54 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh · 1,17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 14,365.67 tonnes deducted reduced CO_2 emissions from alternative electricity production 1,116.542 tonnes.

Total annual amount of greenhouse gas emissions reductions, measured in CO_2 equivalents, associated with the scenario is: 14,365.67 tonnes - 14.48 tonnes * 310 + 37.37 tonnes * 21 + 311.05 tonnes * 3,67 = 11,803 tonnes, and the value of this is equal to 1.45M DKK. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 20 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case as high as 1,694 DKK per tonne CO_2 equivalent.

14.3 Financial analysis

In Table 14.4 the results of the financial analysis pertaining to scenario 4B are presented. As was the case for the welfare economic analysis, reference is made to Chapter 4 and 13 for a detailed description of the principles applied in the calculations. It is seen from the table that the agricultural sector and the local CHP plant are economic winners while the biogas plant and the state both are losers. Of course, as discussed in Section 10.3, it is important to remember that this result to a great extent is the result of the assumptions made about relative prices and about which sectors receive income and bear expenditure burden. Hence, changing these assumptions may lead to changes in the results.

Table 14.4 Calculated financial consequences of biogas production from 50 % cattle slurry and 50 % grass clover at a biogas plant with a treatment capacity of 500 tonnes per day - M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			8.69 M DKK
Production			
- grass clover for fodder	- 9,505,208 FE	1.30 DKK pr FE	-12.36 M DKK
- barley	- 2,278,646 kg	1.5 DKK pr kg	-3.42 M DKK
- triticale	- 2,929,688 kg	1.6 DKK pr kg	-4.69 M DKK
- grass clover for biogas production	19,010,416 FE	1.30 DKK pr FE	24.71 M DKK
Resource use			
- grass clover seed for fodder production	- 11,290 kg	40 DKK pr kg	0.45 M DKK
- barley seed	- 110,667 kg	3.6 DKK pr kg	0.40 M DKK
- triticale seed	- 110,667 kg	3.8 DKK pr kg	0.42 M DKK
- grass clover seed for biogas production	22,580 kg	40 d DKK pr kg	-0.90 M DKK
- labour	-109 hours	150 DKK pr hour	0.02 M DKK
- fuel consumption (diesel)	-1,407 litre	4.3 DKK pr litre	0.01 M DKK
- electricity consumption (watering)	340,739 kWh	0.45 DKK pr kWh	-0.15 M DKK
- labour (irrigation)	117,188 DKK		-0.12 M DKK
- machine costs (incl. irrigation)	203,101 DKK		-0.20 M DKK
- import grass clover, barley, triticale – transport	37,517 km	13.00 DKK pr km	-0.49 M DKK
Agriculture - yield increase			
- barley - treated slurry	1,149 hkg	1.5 DKK pr kg	0.17 M DKK
- triticale - treated slurry	1,149 hkg	1.6 DKK pr kg	0.18 M DKK
- grass clover production - treated slurry	235,954 FE	1.30 DKK pr FE	0.31 M DKK
Fertilizer effect of treated grass clover			
- demand for synthetic fertilizer	- 580 tonnes	7,500 DKK pr tonne	4.35 M DKK
Biogas plant			- 5.52 M DKK
- biogas production for sale	6,038,778 Nm^3	4.4 DKK pr Nm^3	26.57 M DKK
- electricity production for sale	3,672,981 kWh	0.772 DKK pr kWh	2.84 M DKK
- investment costs	5.41 M DKK		- 5.41 M DKK
- construction subsidy	1.08 M DKK		1.08 M DKK
- labour	1 persons' work	320,000 DKK	- 0.32 M DKK
- grass clover consumption	19,010,416 FE	1.30 DKK pr FE	-24.71 M DKK
- electricity consumption	1,186,250 kWh	0.65 DKK pr kWh	- 0.77 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 DKK	- 0.03 M DKK
- service and maintenance	2,373,000 DKK	2,373,000 DKK	- 2.37 M DKK
- transport of slurry and residual	182,500 km	13.00 DKK pr km	-2.37 M DKK
Local CHP plant			1.71 M DKK
- consumption of biogas	6,038,778 Nm^3 natural gas	4.4 DKK pr Nm^3	-26.57 M DKK
- decreased consumption of natural gas	6,038,778 Nm^3 natural gas	1.782 DKK pr Nm^3	10.76 M DKK
- biogas based power production	26,570,624 kWh	0.411 DKK pr kWh	10.92 M DKK
- CO_2 tax exemption	6,038,778 Nm^3 natural gas	0.351 DKK pr Nm^3	2.12 M DKK
- exemption from tax on natural gas for heat	6,038,778 Nm^3 natural gas	0.742 DKK pr Nm^3	4.48 M DKK
The state			-18.6 M DKK
- construction subsidy	1.08 M DKK		- 1.08 M DKK
- biogas based power production	26,570,624 kWh	0.411 DKK pr kWh	- 10.92 M DKK
- CO_2 tax exemption	6,038,778 Nm^3 natural gas	0.351 DKK pr Nm^3	- 2.12 M DKK
- exemption from tax on natural gas for heat	6,038,778 Nm^3 natural gas	0.742 DKK pr Nm^3	- 4.48 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

15 Biogas production from 50 % organic cattle slurry and 50 % organic grass clover at 50 tonnes per day plant, scenario 4C

Scenario 4C is similar to scenarios 4A and 4B in terms of the type of input used for biogas production; hence, slurry from organic dairy cows and organic grass clover each constitute 50 % of the input. The biogas plant is a farm plant with a daily processing capacity of 50 tonnes (18.250 tonnes per year), implying that both the annual slurry input requirement and the annual grass clover input requirement is 9.125 tonnes. This is equivalent to the amount of slurry produced by 339 dairy cows (443 LU's) and the grass clover production from 260 hectares.

As the biogas plant is a farm biogas plants, the assumptions made for scenario 4C regarding the use of the produced biogas are similar to those made in the other farm plant scenarios. Moreover, scenario 4C is similar to the other farm plant scenarios in the sense that no additional transport requirement is associated with the production.

In relation to agriculturally related effects, scenario 4C is similar to scenarios 4A and 4B, only the scale is different due to the smaller treatment capacity of the facility.

In terms of emission changes, changes are induced by the changes in energy production related to the increased production of heat and electricity from biogas and the subsequent displacement of "generic electricity" and oil based heat production. Moreover, emissions changes are also induced by changes in irrigation caused by the changes in crop rotations brought about by the increase in the areas grown with grass clover.

15.1 Consequence description

Table 15.1 contains a list of all the consequences associated with scenario 4C. All the agriculturally related effects of scenario 4C are directly proportional to scenarios 4A and 4B, and therefore the relevant values are listed in the table without further specification. In other cases the situation pertaining to the farm biogas plant differs from that of the joint biogas plants and subsequently the consequences and the way to assess them also differs in some instances. Below the consequences which cannot simply be assessed by simple downscaling of the results from scenario 4A and 2B are explained in more detail.

Table 15.1 Calculated consequences of biogas production from 50 % organic cattle slurry and 50 % grass clover at a farm biogas plant with a treatment capacity of 50 tonnes pr day.

				Consequence per year
Economic consequences				
Agriculture – production				
- grass clover production for fodder				- 950,521 FE = - 4,563 tonnes
- barley production				- 227,865 kg
- triticale production				- 292,969 kg
- grass clover production for biogas production				1,901,042 FE = 9,125 tonnes
Agriculture – resource use				
- grass clover seed for fodder production				- 1,128 kg
- barley seed				- 11,068 kg
- triticale seed				- 11,068 kg
- grass clover seed for biogas production				2,258 kg
- labour				-11 hours
- fuel consumption (diesel)				-141 litre
- electricity consumption (watering)				34,074 kWh
- labour (irrigation)				11,719 DKK
- machine costs (incl. irrigation)				20,310 DKK
Agriculture - yield increase				
- barley production - treated slurry				115 hkg
- triticale production - treated slurry				115 hkg
- grass clover production - treated slurry				23,595 FE
Agriculture – treated grass clover				
- reduced demand for synthetic fertilizer				58 tonnes
Transport				
- import of grass clover, barley and triticale				3,752 km
Biogas plant				
- electricity production for sale (total production)				3,295,348 kWh
- heat production – displaced gasoil				4,200,794 MJ = 117,111 litre gasoil
- investment costs				12.0 M DKK (total amount)
- labour				365 hours
- electricity consumption				119,795 kWh
- water consumption				300 m^3
- chemicals				2,500 DKK
- service and maintenance				399,000 DKK
Emission consequences (tonne)	Total	Agriculture	Transport	Biogas
CO_2	-1,719.296	14.880	3.032	-1,737.208
N_2O	1.443	1.419	0.000	0.024
CH_4	8.248	-4.001	0.000	12.249
C content of soil	31.105	31.105		
Particles	0.009	0.000	0.000	0.009
NO_x	4.613	0.009	0.023	4.581
SO_2	0.174	0.003	0.000	0.171
CO	8.576	0.003	0.004	8.569
NMVOC	0.109	0.001	0.001	0.107
N-leaching	-3.694	-3.694		
Taxes and subsidies -biogas plant/On-site CHP				
- construction subsidy (20 pct.)				2.4 M DKK (total amount)
- reduced demand for gas oil – energy tax				290,318 DKK
- reduced demand for gas oil - CO_2 tax				49,187 DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in DKK are stated in 2009 prices.

15.1.1 Economic consequences

Biogas production per tonne of input is slightly different for the farm biogas compared to the joint biogas plants. The reason for this being that the production process is assumed to be mesophile process rather than thermophile, and that the time that the biomass is in the biogas reactor is longer (50 days compared to 20). The key factors used to calculate biogas production per tonne of input for the farm biogas plant in scenario 4C are listed in Table 15.2.

A daily biomass input of 50 tonnes is equivalent to an annual biomass input of 18,250 tonnes, and with reference to Table 15.2 where the gas production per tonne of input is seen to be equal to 41.04 Nm^3 natural gas equivalents this implies that the gross annual production of the facility amounts to 748,900 Nm^3 natural gas equivalents. Using that the lower heating value of natural gas is 39.6 MJ per Nm^3 this is equivalent to a gross annual production of approximately 29,660,000 MJ.

Table 15.2 Calculated biogas production per tonne of input (50 % cattle slurry and 50 % grass clover at farm biogas plant).

	Cattle slurry	Grass clover
Dry matter (DM) content	8 %	25 %
Kg DM pr tonne	80	250
VS/DM ratio [1]	0,8	0,95
Kg VS pr tonne [1]	64	237,5
Nm^3 CH_4 pr kg VS (HRT=50 days) [1]	0,19	0,33
Nm^3 CH_4 pr tonne	12,16	78,375
CH_4 content of biogas	60 %	60 %
Biogas production (Nm^3 pr tonne)	20,3	130,6
Heating value CH_4 (lower; MJ pr Nm^3)	35,9	35,9
Heating value Natural gas (lower MJ pr Nm^3)	39,9	39,9
Ratio: Natural gas/CH_4	1,1	1,1
Production in natural gas equivalents (Nm^3 pr tonne)	11,1	71,3
Production in natural gas equivalents (Nm^3 pr tonne of input (75 % pig slurry, 25 % maize))		41,04

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be decomposed.

In Table 15.3 it is specified how the produced biogas is used. The process heat requirement for scenario 4C is identical to that applying to scenario 1C.

Table 15.3 Use of biogas production.

Use	Share of gross production (%)	Share in relevant energy equivalents
Gross energy production	100	748,943 Nm^3 Natural gas eq.
Process heat [1]	3.3	991,705 MJ
Electricity for sale [1,2]	40	3.295.348 kWh
Excess heat production [1, 3]	47.2	14,002,646 MJ

1. All heat and electricity production is assumed to be produced at a on-site CHP facility.
2. Electricity for sale is equal to gross electricity production.
3. Of the excess heat production only 30 % are assumed to be used; the remaining 70 % are assumed to be lost.

In contrast to the joint biogas plant scenarios where the biogas production in excess of what is needed to cover the process heat requirement is sold to a local CHP facility the entire biogas production is assumed to be used on the on-plant CHP for the farm biogas plants. The entire amount of electricity (3.295.348 kWh) produced at the CHP is sold. For the heat share of energy production, the heat production in excess of what is required for process heat is equal to 14,002,646 MJ. Of this excess heat production it is assumed that 30 % is put to use on the farm (e.g. for heating of stables and housing), while the remaining 70 % is lost. The 30 % of excess heat production replaces an amount of gasoil equal to 14,002,646 MJ · 0.30 : 35.87 MJ per litre = 117,111 litre gasoil

In Table 15.4 the investment costs for scenario 4C are listed. Following the approach used in the other scenarios the CHP related costs are based on a cost per MJ of 0.075 DKK. With a gross annual production of 748,943 Nm^3 Natural gas equivalents, which is equivalent to approx. 29,660,000 MJ., estimated CHP investment costs becomes approximately 2.2 M DKK.

Table 15.4 Calculated investment costs for farm biogas plant with a capacity of 50 tonnes per day and 50 % cattle slurry and 50 % grass clover as input - M DKK, factor prices.

Storage facilities for grass clover	1.5
Pre-treatment of grass clover	0.5
CHP	2.2
Biogas plant	7.2
Investment costs (A1)	11.4
Projecting/planning costs (5 % of A1)	0.6
Total investment costs	12.0

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

In terms of operating costs, it is seen in Table 15.1 that the time required for operating the plant is set to 365 hours. In addition to this 119,795 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 300 m^3 water. Also different chemicals are needed with factor price value equal to 2,500 DKK. Finally annual service and maintenance costs of the biogas plant are set to 3.5 % of A1 which is equal to 399,000 DKK. The investment and operating cost calculations are based on Petersen (2010).

15.1.2 Emission consequences

The agriculturally related emissions of N_2O and CH_4 emissions from agriculture, and the changes in the C content of the soil and in N-leaching, are directly proportional to the amount of input used for biogas production. Hence, the effects pertaining to scenario 4C are equal to 1/10 of the effects pertaining to scenario 4B.

Emissions consequences related to biogas production and use

The more specific energy related emissions changes pertaining to scenario 4C are listed in table 15.5. The assumptions underlying the calculations are similar to those applied in scenario 1C – see Section 6.1.2.

Table 15.5 Calculated emissions changes from the changes in energy production caused by the production of biogas from 50 % cattle slurry and 50 % grass clover at a farm biogas plant with a daily input capacity of 50 tonnes - tonne.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	TSP	NO_x	SO_2	CO	NMVOC
Biogas based CHP-	Total production	EF (g pr MJ):	0,0000	0,0016	0,4340	0,0026	0,2020	0,0192	0,3100	0,0100
production	(29.658.134 MJ)	Change (tonne):	0,0000	0,0475	12,8716	0,0780	5,9909	0,5694	9,1940	0,2966
Reduced consumption of	Net electricity sale from biogas plant	EF (g pr MJ):	124,7222	0,0018	0,0542	0,0042	0,1042	0,0264	0,0389	0,0111
"generic"-electricity	(11.436.204 MJ)	Change (tonne):	-1.426,3487	-0,0206	-0,6195	-0,0477	-1,1913	-0,3018	-0,4447	-0,1271
Reduced use of oil for heat	Displaced oil-based heat production	EF (g pr MJ):	74,0000	0,0006	0,0007	0,0050	0,0520	0,0230	0,0430	0,0150
production[1]	(4.200.794 MJ)	Change (tonne):	-310,8587	-0,0025	-0,0029	-0,0210	-0,2184	-0,0966	-0,1806	-0,0630
	Total net change in emissions (tonne):		-1.737,2075	0,0243	12,2492	0,0093	4,5812	0,1710	8,5686	0,1065

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity), Nielsen et al. (2010) (biogas) and Danmarks Miljøundersøgelser (2011) (oil).

Note 1: It is assumed that 30 % of the excess heat production is used.

From Table 15.5 it is seen that overall the production of biogas and the associated changes in fuel use in energy production entail net increases in all emissions but CO_2.

15.1.3 Taxes and subsidies

The 20 % construction subsidy apply to scenario 3C due to the fact that it is based on organic input and because it satisfies the requirement of min. 50 % manure, which need to be fulfilled for organic biogas plants to be qualified for the subsidy. Being 20 % of investment costs the subsidy amounts to 2.4 M DKK. for scenario 4C. This corresponds to an annual expense of 147,720 DKK.

As 30 % of the excess heat production at the on-site CHP displaces gasoil consumption the State will lose tax income associated with the consumption of gasoil. More specifically, the government will loose income from a gasoil tax of 2.479 DKK per litre gasoil and a CO_2 tax of 0.42 DKK per litre gasoil. The amount of gasoil displaced in scenario 4C is equal to 117,111 litre and consequently the losses in tax income are estimated to 290,318 DKK (gasoil tax) and 49,187 DKK (CO_2 tax).

The total loss annual loss incurred by the state is 487,226 DKK.

15.2 Welfare economic analysis

In Table 15.6 the welfare economic consequences associated with biogas production according to scenario 4C, their accounting prices, and their resulting welfare economic value are listed. The approaches used in the calculations are similar to those used in scenario 1A; hence, for specification of the calculation principles, reference is made to Chapter 4. Here we solely present the results.

It is seen from the table the total annual welfare economic value of biogas production from 50 % cattle slurry and 50 % grass clover at a biogas plant with a treatment capacity of 50 tonnes pr day is equal to - 1.26 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss, economic consequences account for 1.07 M DKK, emissions consequences for 0.09 M DKK and taxes and subsidies for 0.10 M DKK.

Subsidies and loss of taxes which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 0.1 M DKK to society. This is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases which are the occasion of so-called dead weight losses. If the financing problem is ignored production and use of biogas still lead to a welfare economic loss 1.25 M DKK.

The total annual reduction in greenhouse gas emissions brought about by the scenario is: (1,719.3 - 1.443 *310 - 8.248 * 21 + 31.105 * 3.67) tonnes = 1,213 tonnes CO_2 equivalents, and the value of this reduction is equal to 0.15 M DKK. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 1.41 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case 1,162 DKK per tonne CO_2.

Table 15.6 Calculated welfare economic value of biogas production from 50 % organic cattle slurry and 50 % organic grass clover at a farm biogas plant with a treatment capacity of 50 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 1.07 M DKK
Agriculture – production			
- grass clover production for fodder	- 950,521 FE = - 4,563 tonnes	1.30 DKK pr FE·1.17	- 1.45 M DKK
- barley production	- 227,865 kg	1.5 DKK pr kg·1.17	- 0.4 M DKK
- triticale production	- 292,969 kg	1.6 DKK pr kg·1.17	- 0.55 M DKK
- grass clover production for biogas prod.	1,901,042 FE = 9,125 tonnes		
Agriculture – resource use			
- grass clover seed for fodder production	- 1,128 kg	40 DKK pr kg·1.17	0.05 M DKK
- barley seed	- 11,068 kg	3.6 DKK pr kg·1.17	0.05 M DKK
- triticale seed	- 11,068 kg	3.8 DKK pr kg·1.17	0.05 M DKK
- grass clover seed for biogas production	2,258 kg	40 DKK pr kg·1.17	- 0.11 M DKK
- labour	-11 hours	150 DKK pr hour·1.17	0.00 M DKK
- fuel consumption (diesel)	-141 litre	3.82 DKK pr litre·1.17	0.00 M DKK
- electricity consumption (watering)	34,074 kWh	0.46 DKK pr kWh · 1.17	- 0.02 M DKK
- labour (irrigation)	11,719 DKK	11,719 DKK·1.17	- 0.01 M DKK
- machine costs (incl. irrigation)	20,310 DKK	20,310 DKK·1.17	- 0.02 M DKK
Agriculture - yield increase			
- barley - treated slurry	115 hkg	1.5 DKK pr kg·1.17	0.02 M DKK
- triticale - treated slurry	115 hkg	1.6 DKK pr kg·1.17	0.02 M DKK
- grass clover production - treated slurry	23,595 FE	1.30 DKK pr FE·1.17	0.04 M DKK
Agriculture – treated grass clover			
- reduced demand for synthetic fertilizer	58 tonnes	7,500 DKK pr tonne · 1,17	0.51 M DKK
Transport			
- import of grass clover, barley and triticale	3,752 km	15,22 DKK pr km	- 0.06 M DKK
Biogas plant			
- electricity production for sale	3,295,348 kWh	0.46 DKK prkWh · 1.17	1.77 M DKK
- heat production – displaced gasoil	4,200,794 MJ = 117,111 litre gasoil	110 DKK pr GJ · 1.17	0.54 M DKK
- investment costs	0.74 M DKK	0.74 M DKK · 1.17	- 0.87 M DKK
- labour	365 hours	200 DKK · 1.17	- 0.09M DKK
- electricity consumption	119,795 kWh	0.46 DKK pr kWh · 1.17	- 0.06M DKK
- water consumption	300 m^3	25 DKK pr m^3 · 1,17	- 0.01 M DKK
- chemicals	2,500 DKK	2,500 DKK · 1.17	- 0.00 M DKK
- service and maintenance	399,000 DKK	399,000 DKK · 1.17	- 0.47 M DKK
Emission consequences (tonnes)			- 0.09 M DKK
- CO_2 emissions [1]	-1,719.296 + 999.96	105 DKK pr tonne · 1.17	0.09
- N_2O emissions	1.443	105 DKK pr tonne · 310 · 1.17	-0.05
- CH_4 emissions	8.248	105 DKK pr tonne · 21 · 1.17	-0.02
- C content of soil	31.105	105 DKK pr tonne · 3,67· 1,17	0.01
- particle emissions	0.009		
- NO_x emissions	4.613	55,000 DKK pr tonne	-0.25
- SO_2 emissions	0.174	85,000 DKK pr tonne	-0.01
- CO emissions	8.576		
- NMVOC emissions	0.109		
- N-leaching	-3.694	40,000 DKK pr tonne	0.15
Public net income	- 487,226 DKK	- 487,226 DKK · 0,2	- 0.1 M DKK
Total			- 1.26 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.
Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh · 1,17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 1,719.296 tonnes deducted reduced CO_2 emissions from alternative electricity production 999.96 tonnes.

Below, the individual entries of the welfare economic account are explained.

15.2.1 Value of economic consequences

Generally accounting prices of economic consequences are determined as for scenario 1A – cf. Section 4.2.1 – and scenario 1C (gasoil) – cf. Section 6.2.1.

15.2.2 Value of emission consequences

With regard to determination of accounting prices for emission consequences refer to Section 4.2.2.

15.2.3 Public net income – tax distortion loss

In Section 15.1.3 it was calculated that the public sector will loose annual tax income equal to 487,226 DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 0.1 M DKK.

15.3 Financial analysis

In Table 15.7 the results of the financial analysis pertaining to scenario 4C are presented. Reference is made to Section 4.3 and Section 6.3 for more detailed descriptions of the principles applied in the calculations.

The annual investment costs of 0.89 M DKK are determined by annualizing the investment costs of 12 M DKK over a 25 years life time of the plant and an interest rate of 6 %.

Table 15.7 Financial consequences of biogas production from 50 % cattle slurry and 50 % grass clover at a biogas plant with a treatment capacity of 50 tonnes per day – M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			0.86 M DKK
Production			
- grass clover for fodder	- 950,521 FE	1.30 DKK pr FE	-1.24 M DKK
- barley	- 227,865 kg	1.5 DKK pr kg	-0.34 M DKK
- triticale	- 292,969 kg	1.6 DKK pr kg	-0.47 M DKK
- grass clover for biogas production	1,901,042 FE	1.30 DKK pr FE	2.47 M DKK
Resource use			
- grass clover seed for fodder production	- 1,128 kg	40 DKK pr kg	0.05 M DKK
- barley seed	- 11,068 kg	3.6 DKK pr kg	0.04 M DKK
- triticale seed	- 11,068 kg	3.8 DKK pr kg	0.04 M DKK
- grass clover seed for biogas production	2,258 kg	40 DKK pr kg	-0.10 M DKK
- labour	-11 hours	150 DKK pr hour	0.00 M DKK
- fuel consumption (diesel)	-141 liter	4.3 DKK pr liter	0.00 M DKK
- electricity consumption (watering)	34,074 kWh	0.45 DKK pr kWh	-0.02 M DKK
- labour (irrigation)	11,719 DKK		-0.01 M DKK
- machine costs (incl. irrigation)	20,310 DKK		-0.02 M DKK
- import grass clover, barley, triticale – transport	3,752 km	13.00 DKK pr km	-0.05 M DKK
Agriculture - yield increase			
- barley - treated slurry	115 hkg	1.5 DKK pr kg	0.02 M DKK
- triticale - treated slurry	115 hkg	1.6 DKK pr kg	0.02 M DKK
- grass clover production - treated slurry	23,595 FE	1.30 DKK pr FE	0.03 M DKK
Fertilizer effect of treated grass clover			
- demand for synthetic fertilizer	- 58 ton	7,500 DKK pr tonne	0.44 M DKK
Biogas plant			-0.4 M DKK
- electricity production for sale	3,295,348 kWh	0.772 DKK pr kWh	2.54 M DKK
- heat production – displaced gasoil	4,200,794 MJ = 117,111 litre gasoil	6.845 DKK pr litre	0.80 M DKK
- investment costs	0.89 M DKK		- 0.89 M DKK
- construction subsidy	0.18 M DKK		0.18 M DKK
- labour	365 hours	200 DKK	- 0.07 M DKK
- grass clover consumption	1,901,042 FE	1.30 DKK pr FE	-2.47 M DKK
- electricity consumption	119,795 kWh	0.65 DKK pr kWh	- 0.08 M DKK
- water consumption	300 m^3	25 DKK pr m^3	- 0.01 M DKK
- chemicals	2,500 dkk	2,500 dkk	- 0.00 M DKK
- service and maintenance	399,000 dkk	399,000 dkk	- 0.4 M DKK
The state			- 0.52 M DKK
- reduced demand for gas oil – energy tax	290,318 dkk		- 0.29 M DKK
- reduced demand for gas oil - CO_2 tax	49,187 dkk		- 0.05 M DKK
- construction subsidy	0.18 M DKK		- 0.18 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

16 Scenario 5A: Biogas production from 100 % organic grass clover at 800 tonnes per day plant

In scenario 5A biogas production takes place at a joint biogas plant with a treatment capacity of 800 tonnes per day, and the sole input is organic grass clover. In this connection it is important to note, that this seen from a technical perspective represents a currently unfeasible production approach. Despite this, it has nevertheless been considered relevant to illustrate if there are potential future gains to be realised if technical solutions are devised that enable biogas production based solely on plant inputs with high energy potential such as grass clover. As was the case in scenarios 4, it is assumed that the growing of grass clover for biogas production displace the production of grass clover for forage (50 %), spring barley for forage (25 %) and winter triticale for forage (25 %). Moreover, it is assumed that the growing of crops takes place on sandy soils (JB 1-3 of the Danish soil classification system) with irrigation.

The annual biomass input requirement of the biogas plant is 292.000 tonnes, which is equivalent to the amount of grass clover produced on 8.333 hectares. As was the case in scenarios 4, the required change in land use practices is associated with changes in the use of resources in agricultural production, e.g. changes in the use of labour and machinery.

The fact that 100 % of the input is plant material implies that the transport requirement of scenario 5A is significantly greater than that of scenario 4A. Hence, all transport of biomass to the biogas plant is undertaken by the use of lorries, whereas the transport of biomass from the biogas plant to the farm is undertaken by tank trucks. This implies that both lorries and tank trucks drive empty half of the time. The need for increased import of barley, triticale and grass clover to replace the reduced production of these crops also gives rise to increased transport.

Assumptions made regarding the use of the produced biogas in scenario 5A are similar to the other joint biogas plant scenarios.

With regard to the agriculturally related effects of the scenario it is assumed that the treated grass clover is used as fertiliser in the field, just as it was the case in scenarios 4, where grass clover constituted 50 % of the input. Despite the fact that focus of the scenario is on organic agriculture, biogas production following scenario 5A is expected to result in changed use of synthetic fertiliser and changed N-leaching – following the same argumentation put forward in relation to scenarios 4. The use of treated biomass as fertiliser will also lead to changes in agricultural yields. Moreover, the scenario will be associated with changes in the emissions of CH_4 and N_2O just as it has implications in relation to the C-content of the soil. Hence, the agriculturally related effects of scenario 5 are in many ways similar to those of scenario 4, but the magnitude of the effects is different due to differences in the properties of the input used for biogas production.

As for the other joint biogas plant scenarios, the increased transport requirement associated with the transportation of biomass to and from the biogas plant and increased import of barley, triticale and grass clover along with the substitutions induced in the energy production sector also gives rise to emissions changes. In addition to this changes in electricity consumption brought about by changes in the need for irrigation caused by changes in crop rotations also lead to changes in emissions.

16.1 Consequence description

In Table 16.1 the consequences of biogas production from 100 % organic grass clover at a biogas plant with a treatment capacity of 800 tonnes per day are summarized. The table is divided into three parts covering economic consequences, emissions, and taxes and subsidies respectively.

Below the individual consequences are explained in more detail.

Table 16.1 Calculated onsequences of biogas production from 50 % organic cattle slurry and 50 % grass clover at a biogas plant with a treatment capacity of 800 tonnes per day.

Economic consequences				Consequence per year
Agriculture – production				
- grass clover production for fodder				- 30,416,666 FE = - 146,000 tonnes
- barley production				- 7,291,666 kg
- triticale production				- 9,375,000 kg
- grass clover production for biogas production				60,833,332 FE = 292,000 tonnes
Agriculture – resource use				
- grass clover seed for fodder production				- 36,128 kg
- barley seed				- 354,166 kg
- triticale seed				- 354,166 kg
- grass clover seed for biogas production				72,256 kg
- labour				- 348 hours
- fuel consumption (diesel)				- 4,503 litre
- electricity consumption (irrigation)				1,090,364 kWh
- labour (irrigation)				375,000 DKK
- machine costs (incl. irrigation)				649,924 DKK
Agriculture - yield increase				
- barley production - increased N application				14,720 hkg
- triticale production - increased N application				14,720 hkg
- grass clover production - increased N application				3,022,439 FE
Agriculture – treated grass clover				
- reduced demand for synthetic fertilizer				1,267,388 kg
Transport				
- slurry and grass clover to biogas plant and – residual product to farmers				584,000 km
- import of grass clover, barley and triticale				120,060 km
Biogas plant				
- biogas production for sale				17,525,469 Nm^3
- electricity production for sale				5,876,770 kWh
- investment costs				131.3 M DKK (total amount)
- labour				2 persons' work
- electricity consumption				1,898,000 kWh
- water consumption				1,000 m^3
- chemicals				25,000 DKK
- service and maintenance				4,305,000 DKK
Emission consequences (tonnes)	Total	Agriculture	Transport	Biogas
- CO_2 emissions	-40,140.250	476.130	568.954	-41,185.330
- N_2O emissions	92.170	91.386	0.020	0.767
- CH_4 emissions	138.970	149.385	0.030	-10.440
- C content of soil	2,090.2	2,090.2		
- particle emissions	1.450	0.007	0.068	1.377
- NO_x emissions	60.220	0.291	4.237	55.691
- SO_2 emissions	13.860	0.104	0.004	13.754
- CO emissions	191.500	0.086	0.682	190.729
- NMVOC emissions	-56.400	0.032	0.106	-56.539
- N-leaching	-68.170	-68.165		
Taxes and subsidies CHP plant				
- biogas based power production (subsidy)				31.693 M DKK
- CO_2 tax exemption				6.151 M DKK
- exemption from tax on natural gas for heat production				13.004 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in DKK are stated in 2009 prices.

16.1.1 Economic consequences

Agriculture

The economic consequences for the agricultural sector are shown in Table 16.2. The consequences applying to scenario 5A are basically the same as those applying to scenario 4A, only the scale is different due to the fact that the grass clover input required for biogas production is the double of that in scenario 4A while the slurry input is zero, implying that slurry related effects does not apply to scenario 5A. Unless otherwise specified the consequences are assessed using the same approach as in Chapter 13, hence reference is made to Section 13.1.1. for a more detailed explanation of the calculations.

Table 16.2 Calculated economic consequences of replacing grass clover production for fodder (50 %), spring barley production (25 %) and winter triticale production (25 %) with grass clover production for biogas production on 8,333 hectare land.

	Grass clover production	Barley production	Triticale production	Net change
Agriculture – production				
- grass clover production for fodder	- 30,416,666 FE = - 146,000 tonnes			- 30,416,666 FE
- barley production		- 7,291,666 kg		- 7,291,666 kg
- triticale production			- 9,375,000 kg	- 9,375,000 kg
- grass clover production for biogas production	60,833,332 FE = 292,000 tonnes			60,833,332 FE
Agriculture – resource use				
- grass clover seed for fodder production	- 36,128 kg			- 36,128 kg
- barley seed		- 354,166 kg		- 354,166 kg
- triticale seed			- 354,166 kg	- 354,166 kg
- grass clover seed for biogas production	72,256 kg			72,256 kg
- labour	26,798 hours	- 12,920 hours	- 14,222 hours	348 hours
- fuel consumption (diesel)	346,152 litre	- 166,924 litre	- 183,740 litre	4,503 litre
- electricity consumption (irrigation)	2,725,912 kWh	- 681,878 kWh	- 954,070 kWh	1,090,364 kWh
- labour (irrigation)	937,800 DKK	- 234,450 DKKk	-328,230 DKK	375,000 DKK
- machine costs (incl. irrigation)	9,967,106 DKK	- 4,367,856 DKK	- 4,949,084 DKK	649,924 DKK
Agriculture – yield increase				
- barley - treated grass clover		14,719.67 hkg		
- barley - preceding crop value of grass clover		6,945 hkg		
- triticale - treated grass clover			14,719.67 hkg	
- triticale - preceding crop value grass clover			6,945 hkg	
- grass clover – treated grass clover	3,022,439 FE			
Agriculture – treated grass clover				
- reduced demand for synthetic fertilizer				1,267,388 kg

Source: Based on information about production and resource use per ha in Videncentret for landbrug (2009).

In scenario 4 one of the effects of biogas production is an increase in yield. The cause of the yield increase is an increased share of ammonium N in treated slurry compared to untreated slurry. In scenarios 5 where grass clover constitute the sole input to biogas production this yield increasing effect does not apply. However, another yield increasing effect does apply. Hence, it is assumed that the production of 100 % organic fertilizer – i.e. the treated grass clover – entails an increase in the overall level of N-application within organic agriculture. The background for this assumption being that the level of N-application within organic agriculture generally is restrained by the limited availability of organic fertilizers. This implies that organic farmers have to rely on import of slurry from conventional agriculture as the prime source of N and this import is restricted in the sense that only a certain amount can be applied per ha. This amount is less that the optimal level of N application. More specifically, it is assumed that the production of treated grass clover fertilizer resulting from the production of biogas in scenarios 5, imply that the level of N-application can be increased from 81 kg N per ha to 122 kg N per ha, and this, in turn, lead to an increase in agricultural yields.

Based on a N-content of grass clover of 8 kg N per tonne, the total amount of N in the grass clover treated in scenario 5A is: 8 kg N per tonne · 292,000 tonnes = 2,336,000 kg N and assuming a N-application rate of 122 kg N per ha, the number of hectares fertilized with the treated grass clover is 2,336,000 kg N: 122 kg N per ha = 19,148 hectares. The crop rotation on the affected agricultural land is assumed to be 50 % grass clover, 25 % triticale and 25 % spring barley. For the two cereal crops the yield increase brought about by the increased level of N application is set to 0.11 hkg per kg N made available and the utilization rate of N in the treated material is set to 70 %. The resulting yield increases for each of the two cereal crops therefore becomes 0.1071428 hkg per kg N · (122 kg N per ha - 81 kg N per ha) · 0.7 · 19,147.54 ha · 0.25 = 14,720 hkg. For grass clover the yield increase is set to 11 FE per kg N made available and the utilization rate of N in the treated material is once again set to 70 %. The resulting yield increase for grass clover therefore becomes
11 FE per kg N · (122 kg N per ha - 81 kg N per ha) · 0.7 · 19.147,54 ha · 0.5 = 3,022,439 FE.

Similar to scenarios 4 it is also in scenarios 5 assumed that the grass clover part of the treated biomass when applied to the field as fertilizer displaces imported conventional pig slurry which subsequently displace synthetic fertilizer in conventional agricultural production. Hence, scenarios 5 also indirectly entail a reduction in the application of synthetic fertilizer.

Compared to scenarios 4 where the reduction in the need for slurry was a direct function of the N-content of the treated grass clover plus the amount of N added to the soil due to the nitrogen fixing properties of grass clover (i.e. the preceding crop value effect) the relationship is less straightforward for scenarios 5. Hence, the fact that the substitution of conventional slurry with treated grass clover is assumed to result in an increase in the level of N-application imply that the increase in availability of conventional slurry per tonne of treated grass clover is less in scenarios 5 than it is in scenario 4.

With the preceding crop value effect set to 100 kg N per ha, the total preceding crop value effect for scenario 5A becomes 100 kg N per ha · 4,167 ha : 3 years = 138,900 kg per year. Using that the N-content of grass clover is 8 kg N per tonne and that the total annual grass clover input of the scenario is 292,000 tonne the total annual N-content of the treated grass clover therefore becomes 2,336,000 kg. In total, the amount of N in the treated grass clover and the amount of N made available through crop residues is 2,336,000 kg + 138,900 kg = 2,474,900 kg.

With reference to the preceding account of yield increases the treated grass clover is used as fertilizer on 19,147.54 ha. Assuming that the level of N-application is increased from 81 kg N per ha to 122 kg N per ha - i.e. 41 kg N per ha - this leads to a total increase in the level of N application of 41 kg N per ha · 19,147.54 ha = 785,049 kg N. Deducting the increase in the demand for N following the increased level of N application from the increase in the amount of N made available we get the amount of N which leads to a reduction in the demand for conventional slurry, i.e. 2,474,900 kg N - 785,049 kg N = 1,689,851 kg N. Based on a N-content of pig slurry of 3.931335 kg per tonne the subsequent increase in availability of pig slurry for conventional farming is 1,689,851 kg/3.931335 kg per tonne = 429,841 tonnes. The corresponding reduction in the application of synthetic fertilizer which results from the increased amount of slurry available for application within conventional agriculture is equal to 75 % of the N-content of the slurry - i.e. 1,689,851 kg N · 0.75 = 1,267,388 kg N.

Transport

The key factors used to calculate the transport requirement associated with transport to and from the biogas plant in scenario 4A are listed in Table 16.3 where it also is seen that the total transport requirement is 584,000 km. In connection with the calculations of the biomass related transport requirement for the scenarios involving grass clover it may be noted that the quite high demand for transport is caused by the fact that the lorries used to transport the untreated grass clover cannot drive with return loads - i.e. they drive empty half of the time - and the same is true for the tank trucks transporting the treated grass clover.

It can be seen that the transport requirement is 292,000 tonnes: 30 tonnes · 30 km = 292,000 km for grass clover as well as and treated grass clover. Therefore, total transport requirement is 584,000 km.

Table 16.3 Calculated annual biomass related transport requirement for scenario 5A.

Grass clover to biogas plant (tonnes per year)	292,000
Treated grass clover from biogas plant (tonnes per year)	292,000
Distance between farm and biogas plant (km; one way/return)	15/30
Capacity of tank trucks and lorries (tonnes)	30
No. of return trips tank trucks (treated grass clover)	9,733
No. of return trips lorries (grass clover to biogas plant)	9,733
Total no. of km	584,000

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

As was the case for the scenarios 4 the changes in land use also entail changes in the transport requirements posed by the scenarios 5. In this connection it is assumed that the displaced production is used for animal feed. Denmark is a net importer of animal feed; hence, the decrease in the production of forage crops induced by the production of grass clover for biogas is assumed to result in an increase in the import of animal feed. This increase in import, in turn, is assumed to entail an increase in the need for transport; i.e. the imported feed has to be transported from the border to the place of use.

The key factors used to calculate the more specific increase in the demand for transport brought about by the land use changes associated with scenario 5A, are listed in Table 16.4. – see Section 13.1.1 for a more detailed description of the background for the calculations. As it appears from the table the total increase in the need for transport is estimated to be 120,060 km.

Table 16.4 Calculated changed transport requirement related to displaced production in scenario 5A.

	Grass clover	Triticale	Spring barley
Ha where production is displaced:	4,167	2,083	2,083
Yield per hectare	35	4.5	3.5
Displaced production (tonne)	146,000	9,375	7,292
Effect of decreased production:	Increased import	Increased import	Increased import
Import requirement (tonne):	31,358	9,375	7,292
Capacity of lorries (tonne)	30	30	30
Distance to border (km)	75	75	75
Change in transport requirement (km) [1]	78,395	23,438	18,229
Total change in transport requirement (km)			120,060

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: 1. It is assumed that the transport can be arranged in such a way that the lorries drive with some kind of return load – i.e. the calculated transport requirements reflect only need for one-way trips.

Biogas plant

The key factors used to calculate biogas production per tonne of input is listed in the Table 13.5. Biogas production per tonne of grass clover is identical to the production calculated in relation to scenario 4A equal to 64.8 Nm^3 natural gas equivalents per tonne of grass clover.

Table 16.5 Calculated biogas production per tonne of input (100 % grass clover at joint biogas plant), scenario 5A.

Dry matter (DM) content	25 %
Kg DM tonne	250
VS/DM ratio [1]	0.95
Kg VS pr tonne [1]	237.5
Nm^3 CH_4 pr kg VS (HRT=20 days) [1]	0.3
Nm^3 CH_4 pr tonne	71.25
CH_4 content of biogas	60 %
Biogas production (Nm^3 pr tonne)	118.8
Heating value CH_4 (lower; MJ pr Nm^3)	35.9
Heating value Natural gas (lower; MJ pr Nm^3)	39.9
Ratio: Natural gas pr CH_4	1.1
Production in natural gas equivalents (Nm^3 pr tonne)	64.8

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be decomposed.

The annual biomass input is 292,000 tonnes and with a biogas production of 64.8 Nm^3 natural gas equivalents per tonne biomass input this implies that the gross annual production of the facility amounts to 18,861,098 Nm^3 natural gas equivalents. Using that the lower heating value of natural gas is 39.6 MJ pr Nm^3 this is equivalent to a gross annual production of 746,899,500 MJ.

Table 16.6 Use of biogas production.

	Share of gross production (%)	Share in relevant energy equivalents
Gross energy production	100.0	18,861,098 Nm^3 Natural gas eq.
Process heat [1]	4.2	31,734,560 MJ
Electricity for sale [1]	2.8	5.876.770 kWh
Biogas for sale	92.9	17,525,464 Nm^3 natural gas eq.

Note 1. Process heat and electricity for sale is assumed to be produced at a on-site CHP facility.

In Table 16.6 it is specified how the produced biogas is used. It can be seen from the table that of a total production of 18,861,098 Nm^3 natural gas equivalents biogas about 93 % of it 17,525,464 Nm^3 (694,008,567 MJ) can be sold to a local CHP plant. The remaining 7 % is used for CHP production on the on-plant CHP facility. The necessary amount of process heat (31,734,560 MJ) and the amount of electricity produced together with the process heat (5,876,770 kWh) are identical to the amount in the other 800 tonnes per day scenarios.

The investment cost estimates for scenario 5A are listed in Table 16.7. In this connection it is however relevant to note, that it currently is not feasible to produce biogas based on 100 % grass clover.

Table 16.7 Calculated investment costs for biogas plant with a capacity of 800 tonnes per day and 100 % grass clover as input - M DKK, factor prices.

Buildings, roads, etc.	14.8
Storage facilities for grass clover	50.0
Pre-treatment of grass clover	6.0
Reactors, pipes, etc.	17.8
Gas scrubbers	6.0
CRS (Control, Regulation , Supervision system)	15.2
Pumps etc.	6.3
CHP	3.9
Building site	3.0
Investment costs (A1)	123.0
Gas pipeline	2.1
Projecting/planning costs (5 % of A1)	6.2
Total investment costs	131.3

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

With reference to Table 16.1 operating the biogas plant includes employment of two skilled workmen. In addition to this 1,898,000 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 1,000 m^3 water. Also different chemicals are needed with factor price value equal to 25,000 DKK. In terms of the annual service and maintenance costs of the biogas plant these are set to 3.5 % of A1, which is equal to 4,305,000 DKK. The investment and operating cost calculations are based on Petersen (2010).

16.1.2 Emission consequences

The total emission consequences stated in Table 16.1 are the result of the resource re-allocations described in Section 16.1.1 and like these they can be related to agriculture, transport and biogas production and use respectively. The emissions consequences for each of these three activities are summarized in Table 16.8. In terms of greenhouse gas emissions it is seen that while CO_2 emissions decrease, both CH_4 and N_2O emissions increase. Moreover, the C content of soil is seen to increase thereby adding to the positive climate effect. All other emissions to air except NMVOC increase because of biogas production and increased demand for transport. N-leaching will decrease.

Table 16.8 Calculated emission consequences of biogas production from 100 % organic grass clover at biogas plant with a treatment capacity of 800 tonnes per day - tonnes.

Activities	CO_2	N_2O	CH_4	C content of soil	Particles	NO_x	SO_2	CO	NMVOC	N-leaching
Agriculture – biomass		91.38	149.172	2,090.2						-68.165
Agriculture – energy	476.130	0.006	0.213		0.007	0.291	0.104	0.086	0.032	
Transport – biomass	471.9331	0.017	0.0245		0.0563	3.5144	0.003	0.5663	0.0884	
Transport – barley, triticale	97.021	0.003	0.005		0.012	0.723	0.001	0.116	0.018	
Biogas production and use	-41,185.33	0.7667	-10.4396		1.3772	55.6905	13.7543	190.7293	-56.5389	
Sum	-40,140.25	92.17	138.97	2,090.2	1.45	60.22	13.86	191.50	-56.40	-68.17

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Below the different emission changes are explained in more detail.

Emission consequences related to agriculture

In the present section the changes in N_2O emissions, CH_4 emissions, C-content of the soil and N-leaching associated with scenario 5A are assessed.

The changes in N_2O emissions induced by scenario 5A are related to the emissions from treated grass clover, the changed demand for synthetic fertiliser and the changes in emissions from crop residue caused by the changes in crop rotation. The calculations of changes in N_2O emissions are based on the emissions coefficients specified in Appendix I.

For grass clover there are no emissions in the reference situation because the IPCC methodology does not assign any N_2O-N emission to the N-fixing process itself. For the treated grass clover, however, the N_2O-N emissions coefficient is set to 3 % of the total N-content of the grass clover - i.e. N_2O-N emissions from grass clover increase by 3 % of the total N-content of grass clover when comparing the reference situation with scenario 5A. The total amount of N in the treated grass clover is 8 kg N per tonne 292,000 tonnes = 2,336,000 kg and the increase in N_2O-N emissions consequently becomes $0.03 \cdot 2{,}336{,}000$ kg = 70,080 kg or 70.08 tonnes. Using the conversion factor between N_2O-N and N_2O of 44/28, this translates into an increase in N_2O emissions of 110.126 tonnes.

In Section 16.1.1 the reduction in the demand for synthetic fertiliser brought about by scenario 5A was estimated to 1,267,388 kg. Using that N_2O-N emissions from synthetic fertiliser are 1 % of the N-content of the fertiliser the fertiliser related reduction in N_2O-N emissions for scenario 5A is 12.674 tonnes. The conversion factor between N_2O-N and N_2O is 44/28 and the decrease in N_2O emissions can be calculated as 12.674 tonnes $\cdot 44/28$ = 19.91 tonnes.

Finally, the level of N_2O emissions are also affected by differences in the N-content of the crop residue left on the fields in the biogas scenario (100 % grass clover) and the reference situation (50 % grass clover, 25 % triticale and 25 % spring barley). More specifically, it is estimated that the total annual N_2O emissions will increase by 1.167 tonnes due to changes in the N-content of crop residues.

In total N_2O emissions related to agriculture for scenario 5A increase by 91.38 tonnes compared to the reference situation.

For the grass clover part of the input CH_4 emissions are 0 in the reference situation while they in the biogas scenario are set to 1 % of the gross CH_4 production originating from the plant material (Møller, 2011). The total annual grass clover input of the scenario is 292,000 tonnes, and using that the CH_4 production per tonnes of grass clover is 71.25 m^3 the gross grass clover based CH_4 production of the scenario amounts to 20,805,000 Nm^3. Consequently, the increase in CH_4 emissions is 208,050 Nm^3, which – using that the density of CH_4 is 0.717 kg per Nm^3 – is equivalent to an increase in CH_4 emissions of 149.172 tonnes.

The change in land use induced by the increased demand for grass clover for biogas production also gives rise to changes in the C-content of the soil. The calculations of changes in soil C are based on IPCC (1997) and Olesen (2011). More specifically, the change in soil C induced by the transition to grass clover production in stead of grass clover/triticale/spring barley production is estimated to be 0.21405 tonne per ha - i.e. the soil C content increases following the change in land use. For scenario 5A where 8,333 hectares are used for the production of grass clover for biogas the resulting increase in soil C is 1,783.679 tonnes. In addition to this the C-content of the soil is also affected by the increased yield brought about by the increased level of N-application. More specifically, this is estimated to entail an increase in the C-content of the soil of 306.5 tonnes. In total, the increase in soil C for scenario 5A is 2,090.2 tonnes.

As described in Chapter 13, substitution of synthetic fertiliser with treated grass clover as fertiliser is associated with an increase in the level of N-leaching. More specifically, N-leaching from treated grass clover is assumed to be 0.06 kg N per kg total N applied higher than N-leaching from synthetic fertiliser. The N-content of grass clover is 8 kg per tonne grass clover and with a total annual input of grass clover of 292,000 tonnes the total annual N-content of the treated grass clover becomes 2,336,000 kg. Based on this the increase in N-leaching is 0.06 kg N $\cdot$ 2.336.000 = 140.160 tonnes.

The level of N-leaching is also affected by the changes in land use associated with the scenario. More specifically, N-leaching from a crop rotation with 100 % grass clover is set to 28 kg N per ha while N-leaching from a crop rotation with 50 % cereal crops and 50 % grass clover is set to 53 kg N per ha (Calculated by $N\text{-}LES_4$ (Kristensen et al., 2008)). Hence, the land use changes induced by the scenario actually entail a reduction in N-leaching of 25 kg N per ha. The reduction in N-leaching applies to the 8,333 ha used for producing grass clover for biogas production implying that the total reduction in N-leaching becomes 208.325 tonnes.

In total, the increase in N-leaching due to increased fertilizer level is smaller than the decrease in N-leaching due to changed crop rotation. Thus, in total, scenario 5A is associated with a decrease in N-leaching of 208.325 tonnes – 140.160 tonnes = 68.165 tonnes.

The replacement of grass clover production for fodder (50 %), spring barley production (25 %) and triticale production (25 %) with grass clover production for biogas production (100 %) gives rise to some minor emission consequences related to use of machines and irrigation. These consequences are stated in Table 16.9.

Table 16.9 Calculated emission consequences of replacing grass clover production for fodder (50 %), spring barley production (25 %) and triticale production (25 %) with grass clover production for biogas production (100 %) - tonnes.

	CO_2	N_2O	CH_4	PM	NO_x	SO_2	CO	NMVOC
Emission factors								
Diesel g pr MJ	74.000	0.003	0.001	0.051	0.654	0.002	0.368	0.066
Electricity g pr kWh	449	0.0065	0.195	0.015	0.375	0.095	0.14	0.04
Emissions								
Machines								
- 90,572 MJ diesel	-13.405	-0.001	0.000	-0.009	-0.118	0.000	-0.067	-0.012
+ electricity 1,090,364 kWh	489.535	0.007	0.213	0.016	0.409	0.104	0.153	0.044
Total	476.130	0.006	0.213	0.007	0.291	0.104	0.086	0.032

Source: Changes in emissions from machines are calculated based on emissions coefficients from Winther (2011). Changes in emissions from electricity are based on emissions coefficients from Energinet.DK (2010).

The emission consequences in Table 16.8 are calculated as in scenario 4A – cf. Section 13.1.2 – and they are only doubled compared to this scenario.

Emissions consequences related to transport

The increase in emissions from transporting biomass between farms and biogas plant – total 584,000 km – and the emission increase caused by increased import of barley and triticale – total 120,060 km – are calculated on the basis of the same assumptions about emission coefficients, calorific value of diesel and diesel consumption per km as in scenario 1A – cf. Section 4.1.2.

Emissions consequences related to biogas production and use

The emission changes related to biogas production and use are calculated on the basis of the same method and assumptions about emission coefficients as for scenario 1A in Section 4.1.2. The results for the 100 % grass clover scenario are summarized in Table 16.10.

Table 16.10 Calculated emission consequences from the changes in energy production caused by the production of biogas from 100 % grass clover at a joint biogas plant with a daily input capacity of 800 tonnes – tonnes.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	Particles	NO_x	SO_2	CO	NMVOC
Biogas based CHP-production	Total production (746,899,500 MJ)	EF (g pr MJ):	0.00	0.0016	0.4340	0.0026	0.2020	0.0192	0.3100	0.0100
		Change (tonne):	0	1.1950	324.1544	1.9643	150.8737	14.3405	231.5388	7.4690
Reduced production of electricity with coal as fuel	Net electricity sale from biogas plant (14,323,573 MJ)	EF (g pr MJ):	124.7222	0.0018	0.0542	0.0042	0.1042	0.0264	0.0389	0.0111
		Change (tonne):	-1,786.4679	-0.0259	-0.7759	-0.0597	-1.4920	-0.3780	-0.5570	-0.1592
Reduced use of natural gas at local CHP	Biogas sold to local CHP (694,008,567 MJ)	EF (g pr MJ):	56.7700	0.0006	0.4810	0.0008	0.1350	0.0003	0.0580	0.0920
		Change (tonne):	-39,398.8663	-0.4025	-333.8181	-0.5274	-93.6912	-0.2082	-40.2525	-63.8444
Total net change in emissions			-41,185.3342	0.7667	-10.4396	1.3772	55.6905	13.7543	190.7293	-56.5389

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity) and Nielsen et al. (2010) (biogas and natural gas).

It is seen from Table 16.10 that CO_2, CH_4 and NMVOC emissions will decrease while all other emissions increase.

16.1.3 Taxes and subsidies

Consequences for taxes and subsidies are calculated as in scenario 1A – cf. Section 4.1.3.

In contrast to the joint biogas plants in scenario 1A, 2A, 3A and 4A, the biogas described by scenario 5A is not qualified for a 20 % construction subsidy. Hence, for organic based biogas plants manure must constitute minimum 50 % of the input for the plant to qualify for receiving the subsidy.

Finally use of biogas at the local CHP plant is also subsidized in different ways which depends on the amount of power produced and amount of biogas replaced – see Section 3.1. The amount of biogas produced which replaces natural gas at the local CHP is equal to 17,525,469 Nm^3. It has a calorific value of 694,008,567 MJ. Assuming that the local CHP has an efficiency of power production of 40 pct. the annual electricity production can be calculated as 694,008,567 MJ 0.40 : 3.6 kWh per MJ = 77,112,063 kWh.

Biogas based power production is subsidized with 0.411 DKK. per kWh. So the production of 77,112,063 kWh increases government annual expenditures with 31.693 M DKK. In addition to this the local CHP plant receives tax exemption from both CO_2 tax and from tax on natural gas replaced for heat production. The tax rates are equal to 0.351 dkk and 0.742 DKK per Nm^3 of natural gas replaced at the CHP plant respectively – cf. Section 3.1. So, the total value of tax exemption can be calculated as 17,525,469 Nm^3 (0.351 + 0.742) DKK per Nm^3 = 19.155 M DKK. This amount of money means a loss of income to the government.

In total the government annual net expenditures are increased with 50.848 M DKK. This amount is important for the welfare economic calculations, because it represents a so-called tax distortion loss. Of course, the subsidies and tax exemptions are also important for the financial calculations which inter alia show how the economic situation of biogas plant and local CHP plant is affected by the biogas production and use.

16.2 Welfare economic analysis

In Table 16.11 the consequences, accounting prices and welfare economic value of consequences of biogas production based on 100 % organic grass clover at a biogas plant with a treatment capacity of 800 tonnes per day are shown. It is seen from the table that the total annual welfare economic value of biogas production is equal to - 51.33 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss economic consequences, emission consequences and taxes and subsidies account for 41,17 M DKK, -0.01 M DKK and 10.17 M DKK respectively. Especially the loss of agricultural production, the fertilizer value of the treated grass clover, transport costs and the value of biogas are important for the total result.

Subsidies and loss of taxes, which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 10.17 M DKK to society. As mentioned earlier this is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases, which are the occasion of so-called dead weight losses. However, other financing possibilities which do not lead to dead weight losses are possible, but even if the financing problem is ignored production and use of biogas on the basis on grass clover still lead to a welfare economic loss 41.16 M DKK.

The total annual reduction in greenhouse gas emissions entailed by the scenario is: (40,140.25 – 92.17 310 – 138.97 21 + 2,090.2 3.67) tonnes = 16,320 tonnes CO_2 equivalents. Hence, despite the fact that the annual reduction in CO_2 emissions in this case is as high as 40 tonnes (primarily due to biogas being regarded as a CO_2 neutral fuel) the total decrease in climate gas emission is quite low due to corresponding large increases in N_2O and CH_4 emissions. These increases are caused by high N_2O emissions from treated grass clover and CH_4 emissions from grass clover used in biogas production. The value of the decrease in climate gas emissions is equal to 2 M DKK and if this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 53.33 M DKK to obtain the indicated climate gas emission reduction. Hence, the implied price of CO_2 reductions is in this case as high as 3,268 DKK per tonne CO_2 equivalent.

Table 16.11 Calculated welfare economic value of biogas production from 100 % organic grass clover at a biogas plant with a treatment capacity of 800 tonnes per day - M DKK.

	Consequence per yea	Accounting price	Welfare economic value
Economic consequences			- 41.17 M DKK
Agriculture – production			
- grass clover production for fodder	- 30,416,666 FE = - 146,000 tonnes	1.30 DKK pr FE·1.17	- 46.26 M DKK
- barley production	- 7,291,666 kg	1.5 DKK pr kg·1.17	- 12.80 M DKK
- triticale production	- 9,375,000 kg	1.6 DKK pr kg·1.17	- 16.45 M DKK
- grass clover production for biogas production	60,833,332 FE = 292,000 tonnes		
Agriculture – resource use			
- grass clover seed for fodder production	- 36,128 kg	40 DKK pr kg·1.17	1.69 M DKK
- barley seed	- 354,166 kg	3.6 DKK pr kg·1.17	1.49 M DKK
- triticale seed	- 354,166 kg	3.8 DKK pr kg·1.17	1.57 M DKK
- grass clover seed for biogas production	72,256 kg	40 DKK pr kg·1.17	- 3.38 M DKK
- labour	- 348 hours	150 DKK pr hour·1.17	0.06 M DKK
- fuel consumption (diesel)	- 4,503 litre	3.82 DKK pr litre·1.17	0.02 M DKK
- electricity consumption ()	1,090,364 kWh	0.46 DKK prkWh · 1.17	- 0,59 M DKK
- machine services and labour	375,000 DKK	375,000 DKK·1.17	- 0.44 M DKK
- maintenance of machines (incl.)	649,924 DKK	649,924 DKK·1.17	- 0.76 M DKK
Agriculture - yield increase			
- barley - increased N application	14,720 hkg	1.5 DKK pr kg·1.17	2.58 M DKK
- triticale - increased N application	14,720 hkg	1.6 DKK pr kg·1.17	2.76 M DKK
- grass clover production - increased N application	3,022,439 FE	1.30 DKK pr FE·1.17	4.60 M DKK
Agriculture – treated grass clover			
- reduced demand for synthetic fertilizer	1,267,388 kg	7,500 DKK pr tonne · 1,17	11.12 M DKK
Transport			
- slurry and grass clover to biogas plant and residual product to farmers	584,000 km	15,22 DKK pr km	- 8.89 M DKK
- import of grass clover, barley and triticale	120,060 km	15,22 DKK pr km	- 1.82 M DKK
Biogas plant			
- biogas production for sale	17,525,469 Nm^3	1.8 DKK pr Nm^3 · 1.17	36.91 M DKK
- electricity production for sale	5,876,770 kWh	0.46 DKK pr kWh · 1.17	3.16 M DKK
- investment costs	131.3 M DKK (total amount)	8.08 M DKK · 1.17	- 9.46 M DKK
- labour	2 persons' work	320,000 DKK · 1.17	- 0.75 M DKK
- electricity consumption	1,898,000 kWh	0.46 DKK pr kWh · 1.17	- 1.02 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3 · 1,17	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 DKK · 1.17	- 0.03 M DKK
- service and maintenance	4,305,000 DKK	4,305,000 DKK · 1.17	- 5.04 M DKK

Continued			
Emission consequences (tonne)			0.01 M DKK
- CO_2 emissions [1]	-40,140.250 + 1,917,576	105 DKK pr tonne · 1.17	4.70
- N_2O emissions	92.170	105 DKK pr tonne · 310 · 1.17	-3.51
- CH_4 emissions	138.970	105 DKK pr tonne tonne · 21 · 1.17	-0.36
- C content of soil	2,090.2	105 DKK pr tonne tonne · 3,67· 1,17	0.94
- particle emissions	1.450		
- NO_x emissions	60.220	55,000 DKK pr tonne	-3.31
- SO_2 emissions	13.860	85,000 DKK pr tonne	-1.18
- CO emissions	191.500		
- NMVOC emissions	-56.400		
- N-leaching	-68.170	40,000 DKK pr tonne	2.73
Public net income	- 50.85 M DKK	- 50.85 M DKK · 0,2	- 10.17 M DKK
Total			- 51.33 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh 1,17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 40,140.250 tonnes deducted reduced CO_2 emissions from alternative electricity production 1,917.576 tonnes.

It is also seen from the table that the costs to society of increased NO_x and SO_2 emissions (due to higher NO_x and SO_2 emission coefficients for biogas than for natural gas) are higher than the value of reduced climate gas emissions. N-leaching, on the other hand represents a significant welfare gain to society. However, in total the value of environmental consequences is negative. So, nothing seems to indicate that biogas production at a 800 tonnes production plant based on 100 % organic grass clover is welfare economically favourable to society.

In fact, compared to biogas production based on all the other considered inputs 100 % grass clover seems to be the least favourable; this, to some extent, is somewhat surprising considering that grass clover has the highest biogas production per tonne of input. The most important reasons for the result is the high value of the lost agricultural production, the higher production costs of grass clover compared to those of barley and triticale and the high increase in the need for transport. The value of these losses by far exceeds the value of increased yields in agriculture, increased biogas production and decreased need of N fertilizer.

Below, the individual entries of the welfare economic account are explained in detail.

16.2.1 Value of economic consequences

The basis for estimation of accounting prices in welfare economic analysis is explained in Section 4.2.1 and all the relevant accounting prices of economic consequences for scenario 5A are explained in relation to scenario 4A - cf. Section 13.2.1.

16.2.2 Value of emission consequences

The value of emission consequences is calculated with the same welfare economic accounting prices as in scenario 1A - cf. Section 4.2.2

16.2.3 Public net income – tax distortion loss

In Section 16.1.3 it was calculated that the public sector will loose annual tax income equal to 50.8 M DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 10.16 M DKK.

16.3 Financial analysis

In Table 16.12 it is shown how the financial circumstances of the involved economic sectors are affected. It is seen from the table that the agricultural sector and the local CHP plant are economic winners while the biogas plant and the state both are losers. Of course, this result depends on assumptions about relative prices and about which sectors receive income and bear expenditure burden. Thus, it is assumed that the biogas plant pays a price for organic grass clover equal to its internal price per FE. This is the main reason why the agricultural sector gets a profit from changing land use with a view to deliver grass clover for biogas production. Of course changing land use also increases resource consumption and import of barley and triticale, but these costs are partly compensated by the value of increased yields and saved synthetic fertilizer when treated grass clover displaces pig slurry as fertilizer.

Table 16.12 Calculated financial consequences of biogas production from 100 % organic grass clover at a biogas plant with a treatment capacity of 800 tonnes per day - M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			29.76 M DKK
Production			
- grass clover for fodder	- 30,416,666 FE	1.30 DKK pr FE	-39.54 M DKK
- barley	- 7,291,666 kg	1.5 DKK pr kg	-10.94 M DKK
- triticale	- 9,375,000 kg	1.6 DKK pr kg	-15.00 M DKK
- grass clover for biogas production	60,833,332 FE	1.30 DKK pr FE	79.08 M DKK
Resource use			
- grass clover seed for fodder production	- 36,128 kg	40 DKK pr kg	1.45 M DKK
- barley seed	- 354,166 kg	3.6 DKK pr kg	1.28 M DKK
- triticale seed	- 354,166 kg	3.8 DKK pr kg	1.34 M DKK
- grass clover seed for biogas production	72,256 kg	40 DKK pr kg	-2.89 M DKK
- labour	- 348 hours	150 DKK pr hour	0.05 M DKK
- fuel consumption (diesel)	- 4,503 litre	4.3 DKK pr litre	0.02 M DKK
- electricity consumption (irrigation)	1,090,364 kWh	0.45 DKK pr kWh	-0.50 M DKK
- labour (irrigation)	375,000 DKK		-0.38 M DKK
- machine costs (incl. irrigation)	649,924 DKK		-0.65 M DKK
- import grass clover, barley, triticale – transport	120,060 km	13.00 DKK prkm	-1.56 M DKK
Agriculture - yield increase			
- barley - increased N application	14,720 hkg	1.5 DKK pr kg	2.21 M DKK
- triticale - increased N application	14,720 hkg	1.6 DKK pr kg	2.36 M DKK
- grass clover production - increased N application	3,022,439 FE	1.30 DKK pr FE	3.93 M DKK
Fertilizer effect of treated grass clover			
- demand for synthetic fertilizer	-1,267 tonnes	7,500 DKK pr tonne	9.50 M DKK
Biogas plant			- 20.76 M DKK
- biogas production for sale	17,525,469 Nm^3 natural gas	4.4 DKK pr Nm^3	77.11 M DKK
- electricity production for sale	5,876,770 kWh	0.772 DKK pr kWh	4.54 M DKK
- investment costs	9.69 M DKK		- 9.69 M DKK
- labour	2 persons' work	320,000 DKK	- 0.64 M DKK
- grass clover consumption	60,833,332 FE	1.30 DKK pr FE	- 79.08 M DKK
- electricity consumption	1,898,000 kWh	0.65 DKK pr kWh	- 1.04 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 DKK	- 0.03 M DKK
- service and maintenance	4,305,000 DKK		- 4.31 M DKK
- transport of slurry and residual	584,000 km	13.00 DKK pr km	-7.59 M DKK
Local CHP plant			4.96 M DKK
- consumption of biogas	17,525,469 Nm^3 natural gas	4.4 DKK pr Nm^3	- 77.11 M DKK
- decreased consumption of natural gas	17,525,469 Nm^3 natural gas	1.782 DKK pr Nm^3	31.23 M DKK
- biogas based power production	77,112,063 kWh	0.411 DKK pr kWh	31.69 M DKK
- CO_2 tax exemption	17,525,469 Nm^3 natural gas	0.351 DKK pr Nm^3	6.15 M DKK
- exemption from tax on natural gas for heat	17,525,469 Nm^3 natural gas	0.742 DKK pr Nm^3	13.00 M DKK
The state			- 50.84 M DKK
- biogas based power production	77,112,063 kWh	0.411 DKK pr kWh	- 31.69 M DKK
- CO_2 tax exemption	17,525,469 Nm^3 natural gas	0.351 DKK pr Nm^3	- 6.15 M DKK
- exemption from tax on natural gas for heat	17,525,469 Nm^3 natural gas	0.742 DKK pr Nm^3	- 13.00 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

The biogas plant has a deficit because it has to pay the assumed internal price for grass clover. Perhaps it is possible to agree with suppliers about a lower price, as these gets a profit, but unless the price is lowered very much the biogas plant is still likely to have a deficit.

If the agricultural sector and the local CHP plant pay some of the transport costs, the agricultural sector charge a price lower than the internal price for grass clover used for biogas production and the local CHP plant pays a higher price for biogas it seems to be possible to cover most the economic loss of the biogas plant. However, in any case the state will lose tax income and have increased expenditures for subsidies and therefore, the production and use of biogas will inflict financial loses on at least one of the involved economic sectors.

Of course the state can choose to accept its financial losses because of the reduction in climate gas emissions which is the most important result of biogas production and use. However, as the welfare economic analysis has shown the value to society of these emission reductions is not big enough to justify the welfare economic costs of biogas production.

In the following section the financial calculations are explained in more detail.

16.3.1 Agriculture

It is seen from Table 16.12 that the agricultural sector annually gets a profit equal to 29.76 M DKK. The profit is due to higher net income from grass clover production than for barley and triticale production, increased yields when slurry is replaced by treated grass clover from the biogas production as fertilizer and reduced consumption of synthetic fertilizer because pig slurry is made available when treated grass clover and slurry are used as fertilizer. The price of grass clover of 1.30 DKK per FE is an estimated internal price, because grass clover for fodder is not a traded crop - cf. Videncentret for landbrug (2009). All other prices and amounts in dkk are also based on Videncentret for landbrug (2009).

16.3.2 Biogas plant

The biogas plant is expected to get an annual net deficit of 18.86 M DKK. The prices used in the calculations are factor prices including not refunded taxes which were the basis for determination of accounting prices in the welfare economic analysis – cf. Section 4.2.1. The financial result for the biogas plant is based on three important assumptions that have been discussed above.

First the biogas plant pays the internal price for grass clover. Alternatively it could have been assumed that grass clover for biogas production is traded to a lower price. This is a possibility because to the given prices the agricultural sector will earn a profit by substituting barley and triticale production with grass clover production and use treated grass clover as fertilizer.

Second the biogas plant pays for transport of grass clover from farmers to biogas plant and treated grass clover from the biogas plant to farmers. Alternatively it could have been assumed that transport is totally or partly paid by farmers because they earn a profit.

Third the biogas plant gets a price for biogas (measured in natural gas equivalents) equal to the natural gas price. This assumption can also be discussed because, as explained below, the local CHP plant which buys the biogas makes a net profit by replacing natural gas with biogas. Therefore, it can be argued that the local CHP plant will be willing to pay a higher price for biogas than assumed - still taking into account that biogas is not as flexible as natural gas as fuel. A higher biogas price will of course increase the profit of the biogas plant and reduce the economic advantage for the local CHP plant. Thus, the biogas price is a decisive factor of the distribution of a potential financial profit of biogas production.

With regard to the assumptions about electricity prices and annual investment costs see Section 4.3.2 for further explanation.

16.3.3 Local CHP plant

Apart from increasing expenses due to the purchase of biogas and decreased expenses for buying natural gas the financial circumstances of the local CHP plant are only affected by the subsidy to biogas based power production and exemptions from CO_2 tax and tax on natural gas for heat production. Based on the same assumptions about subsidy to biogas based power production and tax exemption from CO_2 tax and biogas used for heat production as stated in Section 4.1.3 the local CHP plant earns an annual profit of 4.96 M DKK. However, the precondition for this profit is that the plant can buy biogas for the same price as natural gas.

16.3.4 The State

The state has increasing expenditures because of subsidy to biogas based power production at the local CHP plant. In addition to this the state loses tax income from fertilizer tax, CO_2 tax and tax on natural gas for heat production. In total net expenditures of the state are increased with 50.84 M DKK.

17 Scenario 5B: Biogas production from 100 % organic grass clover at 500 tonnes per day plant

Apart from the processing capacity of the biogas plant, and the assumed distance between the biogas plant and the input supplying farms, scenario 5B is identical to scenario 5A. The daily input capacity of the considered plant is 500 tonnes, which is equivalent to an annual input of 182.500 tonnes of grass clover. This corresponds to amount of grass clover being produced on 5,208 hectares. In terms of the assumed average distance between the farms supplying the slurry and the biogas production plant, it is assumed that it is 10 km, similar to what has been assumed for the other 500 tonnes per day plants.

17.1 Consequence description

All consequences associated with scenario 5B except 1) investment and operating costs, and 2) the costs of transporting input to biogas production (including transport related emissions) are directly proportional to the amount of input used for biogas production and can therefore be assessed by a simple downscaling of the changes estimated for scenario 5A. More specifically, the changes applying to scenario 5B are calculated by multiplying the changes assessed for scenario 5A by 0,625 (i.e. 500 tonnes per day/800 tonnes per day = 0,625).

The consequences of scenario 5B are listed in Table 17.1. For the consequences which are assessed by simple downscaling, the relevant values for scenario 5B are simply listed in the table; for descriptions of the consequences and the approaches used to quantify them reference is made to the previous chapters. The transport related consequences and the investment and operating costs applying to scenario 5B are assessed in the following sections.

Table 17.1 Calculated consequences of biogas production from 50 % cattle slurry and 25 % grass clover at farm biogas plant with a treatment capacity of 50 tonnes per day.

Economic consequences	Consequence per year
Agriculture – production	
- grass clover production for fodder	- 19,010,416 FE = - 91,250 tonnes
- barley production	- 4,557,291 kg
- triticale production	- 5,859,375 kg
- grass clover production for biogas production	38,020,833 FE = 182,500 tonnes
Agriculture – resource use	
- grass clover seed for fodder production	- 22,580 kg
- barley seed	- 221,354 kg
- triticale seed	- 221,358 kg
- grass clover seed for biogas production	45,160 kg
- labour	- 218 hours
- fuel consumption (diesel)	- 2,814 litre
- electricity consumption (irrigation)	681,478 kWh
- labour (irrigation)	234,375 DKK
- machine costs (incl. irrigation)	406,203 DKK
Agriculture - yield increase	
- barley production – increased N application	9,200 hkg
- triticale production - increased N application	9,200 hkg
- grass clover production - increased N application	1,889,024 FE
Agriculture – treated grass clover	
- reduced demand for synthetic fertilizer	792,118 kg
Transport	
- grass clover to biogas plant and – residual product to farmers	243,333 km
- import of grass clover, barley and triticale	75,038 km
Biogas plant	
- biogas production for sale	10,953,418 Nm^3
- electricity production for sale	3,672,981 kWh
- investment costs	93.2 M DKK (total amount)
- labour	1 persons' work
- electricity consumption	1,186,250 kWh
- water consumption	1,000 m^3
- chemicals	25,000 DKK
- service and maintenance	3,038,000 DKK

Emission consequences (tonne)	Total	Agriculture	Biogas	Transport - biomass for biogas	Transport - displaced production
- CO_2	-25,185.97	297.581	-25,740.83	196.639	60.639
- N_2O	57.61	57.116	0.48	0.007	0.002
- CH_4	86.85	93.366	-6.53	0.01	0.003
- C content of soil	1,306.4	1,306.4			
- particles	0.89	0.004	0.86	0.023	0.007
- NO_x	36.91	0.182	34.81	1.464	0.452
- SO_2	8.67	0.065	8.60	0.001	0.000
- CO	119.57	0.054	119.21	0.236	0.073
- NMVOC	-35.27	0.020	-35.34	0.037	0.011
- N-leaching	-42.60	-42.603			

Taxes and subsidies	
CHP plant	
- biogas based power production (subsidy)	- 19.808 M DKK
- CO_2 tax exemption	- 3.844 M DKK
- exemption from tax on natural gas for heat production	- 8.128 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in DKK are stated in 2009 prices.

Transport

As mentioned in the beginning of the chapter, the distance between the farms supplying the input and the biogas plant are assumed to be 10 km in scenario 5B. As in scenario 5A lorries with a capacity of 30 tonnes are used to transport the untreated grass clover while tank trucks also with a capacity of 30 tonnes are used to transport the treated biomass. With an annual slurry input of 182,500 the total annual transport requirement is: 2*(182,500 tonnes : 30 tonnes * 20 km) = 243,333 km.

The transport related emissions consequences of scenario 5B are assessed using the same emissions coefficients as in the previous scenarios, and the resulting emissions changes are listed in Table 17.1.

Investment and operating costs

The estimated investment costs for scenario 5B are listed in Table 17.2 where it is seen that total investment costs amount to 93.2 M DKK.

Table 17.2 Calculated investment costs for biogas plant with a capacity of 500 tonnes per day and 100 % grass clover as input - M DKK, factor prices.

Buildings, roads, etc.	11.5
Storage facilities for grass clover	34.0
Pre-treatment of grass clover	4.0
Reactors, pipes, etc.	11.1
Gas scrubbers	4.7
CRS (Control, Regulation , Supervision system)	11.8
Pumps etc.	4.9
CHP	2.5
Building site	2.3
Investment costs (A1)	*86.8*
Gas pipeline	2.1
Projecting/planning costs (5 % of A1)	4.3
Total investment costs	*93.2*

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

In terms of operating costs, it is seen in Table 17.1 that operating the biogas plant is assumed to require the employment of 1 skilled workman. In addition to this 1,186,250 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 1,000 m^3 water. Also different chemicals are needed with factor price value equal to 25,000 DKK. Finally annual service and maintenance costs of the biogas plant are set to 3.5 % of A1 which is equal to 3,038,000 DKK. The investment and operating cost calculations are based on Petersen (2010).

17.2 Welfare economic analysis

In Table 17.3 the welfare economic consequences associated with biogas production according to scenario 5B, their accounting prices, and their resulting welfare economic value are listed. The approaches used in the calculations are similar to those used in scenario 1A and 5A; hence, for specification of the calculation principles, reference is made to chapters 4 and 16. Here we solely present the results. It is seen from the table the total annual welfare economic value of biogas production is equal to - 32.33 M DKK. This means that it is a welfare economic loss for society to start this production.

Of the total loss, economic consequences account for 26.04 M DKK, emissions consequences for -0.07 M DKK and taxes and subsidies for 6.36 M DKK.

Table 17.3 Calculated welfare economic value of biogas production from 100 % organic grass clover at a biogas plant with a treatment capacity of 500 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 26.04 M DKK
Agriculture – production			
- grass clover production for fodder	- 19,010,416 FE = - 91,250 tonnes	1.30 DKK pr FE·1.17	- 28.91 M DKK
- barley production	- 4,557,291 kg	1.5 DKK pr kg·1.17	- 8.00 M DKK
- triticale production	- 5,859,375 kg	1.6 DKK pr kg·1.17	- 10.97 M DKK
- grass clover production for biogas production	38,020,833 FE = 182,500 tonnes		
Agriculture – resource use			
- grass clover seed for fodder production	- 22,580 kg	40 DKK pr kg·1.17	1.06 M DKK
- barley seed	- 221,354 kg	3.6 DKK pr kg·1.17	0.93 M DKK
- triticale seed	- 221,358 kg	3.8 DKK pr kg·1.17	0.98 M DKK
- grass clover seed for biogas production	45,160 kg	40 DKK pr kg·1.17	- 2.11 M DKK
- labour	- 218 hours	150 DKK pr hour·1.17	0.04 M DKK
- fuel consumption (diesel)	- 2,814 litre	3.82 DKK pr litre·1.17	0.01 M DKK
- electricity consumption (watering)	681,478 kWh	0.46 DKK pr kWh · 1.17	- 0.37 M DKK
- machine services and labour watering	234,375 DKK	234,375 DKK·1.17	- 0.27 M DKK
- maintenance of machines (incl. watering)	406,203 DKK	406,203 DKK·1.17	- 0.48 M DKK
Agriculture - yield increase			
- barley - increased N-application	9,200 hkg	1.5 DKK pr kg·1.17	1.61 M DKK
- triticale - increased N-application	9,200 hkg	1.6 DKK pr kg·1.17	1.73 M DKK
- grass clover production - increased N-application	1,889,024 FE	1.30 DKK pr FE·1.17	2.88 M DKK
Agriculture – treated grass clover			
- reduced demand for synthetic fertilizer	792,118 kg	7,500 DKK pr tonne · 1,17	6.95 M DKK
Transport			
- slurry and grass clover to biogas plant and residual product to farmers	243,333 km	15,22 DKK pr km	- 3.70 M DKK
- import of grass clover, barley and triticale	75,038 km	15,22 DKK pr km	- 1.14 M DKK
Biogas plant			
- biogas production for sale	10,953,418 Nm^3	1.8 DKK pr Nm^3 · 1.17	23.07 M DKK
- electricity production for sale	3,672,981 kWh	0.46 DKK pr kWh · 1.17	1.98 M DKK
- investment costs	93.2 M DKK (total amount)	5.74 M DKK · 1.17	- 6.71 M DKK
- labour	1 persons' work	320,000 DKK · 1.17	- 0.37 M DKK
- electricity consumption	1,186,250 kWh	0.46 DKK pr kWh · 1.17	- 0.64 M DKK
- water consumption	1,000 m^3	25 DKK pr m^3 · 1,17	- 0.03 M DKK
- chemicals	25,000 DKK	25,000 DKK · 1.17	- 0.03 M DKK

Continued			
- service and maintenance	3,038,000 DKK	3,038,000 DKK · 1.17	- 3.55 M DKK
Emission consequences (ton)			0.07 M DKK
- CO_2 emissions [1]	-25,185.97 + 1,116,54	105 DKK pr tonne · 1.17	2.96
- N_2O emissions	57.61	105 DKK pr tonne · 310 · 1.17	-2.19
- CH_4 emissions	86.85	105 DKK pr tonne · 21 · 1.17	-0.22
- C content of soil	1,306.4	105 DKK pr tonne · 3,67· 1,17	0.59
- particle emissions	0.89		
- NO_x emissions	36.91	55,000 DKK pr tonne	-2.03
- SO_2 emissions	8.67	85,000 DKK pr tonne	-0.74
- CO emissions	119.57		
- NMVOC emissions	-35.27		
- N-leaching	-42.60	40,000 DKK pr tonne	1.70
Public net income	- 31.78 M DKK	- 31.78 M DKK · 0,2	- 6.36 M DKK
Total			- 32.33 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh · 1,17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 25,185.97 tonnes deducted reduced CO_2 emissions from alternative electricity production 1,116.54 tonnes.

Total annual amount of greenhouse gas emissions reductions, measured in CO_2 equivalents, associated with the scenario is: 25,185.97 tonnes - 57.61 tonnes · 310 - 86.85 tonnes · 21 + 1,306.4 tonnes · 3.67 = 10,297 tonnes, and the value of this is equal to 1.27 M DKK. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 33.6 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case as high as 3,263 DKK per tonne CO_2 equivalent.

17.3 Financial analysis

In Table 17.4 the results of the financial analysis pertaining to scenario 5B are presented. As was the case for the welfare economic analysis, reference is made to chapter 4 and 16 for a detailed description of the principles applied in the calculations. It is seen from the table that the agricultural sector and the local CHP plant are economic winners while the biogas plant and the state both are losers. Of course, as discussed in Section 10.3, it is important to remember that this result to a great extent is the result of the assumptions made about relative prices and about which sectors receive income and bear expenditure burden. Hence, changing these assumptions may lead to changes in the results.

Table 17.4 Calculated financial consequences of biogas production from 100 % grass clover at a biogas plant with a treatment capacity of 500 tonnes per day - M DKK.

	Consequence per year	Price	Income and expenditures, M DKK
Agriculture			18.59
Production			
- grass clover for fodder	- 19,010,416 FE	1.30 DKK pr FE	-24.71
- barley	- 4,557,291 kg	1.5 DKK pr kg	-6.84
- triticale	- 5,859,375 kg	1.6 DKK pr kg	-9.38
- grass clover for biogas production	38,020,833 FE	1.30 DKK pr FE	49.43
Resource use			
- grass clover seed for fodder production	- 22,580 kg	40 DKK pr kg	0.90
- barley seed	- 221,354 kg	3.6 DKK pr kg	0.8
- triticale seed	- 221,358 kg	3.8 DKK pr kg	0.84
- grass clover seed for biogas production	45,160 kg	40 DKK pr kg	-1.81
- labour	- 218 hours	150 DKK pr hour	0.03
- fuel consumption (diesel)	- 2,814 litre	4.3 DKK pr litre	0.01
- electricity consumption (watering)	681,478 kWh	0.45 DKK pr kWh	-0.31
- machine services and labour watering	234,375 DKK		-0.23
- maintenance of machines (incl. watering)	406,203 DKK		-0.41
- import grass clover, barley, triticale – transport	75,038 km	13.00 DKK pr km	-0.98
Agriculture - yield increase			
- barley - increased N-application	9,200 hkg	1.5 DKK pr kg	1.38
- triticale - increased N-application	9,200 hkg	1.6 DKK pr kg	1.47
- grass clover production - increased N-application	1,889,024 FE	1.30 DKK pr FE	2.46
Fertilizer effect of treated grass clover			
- demand for synthetic fertilizer	792 tonnes	7,500 DKK pr tonne	5.94
Biogas plant			-12.61
- biogas production for sale	10,953,418 Nm^3	4.4 DKK pr Nm^3	48.20
- electricity production for sale	3,672,981 kWh	0.772 DKK pr kWh	2.84
- investment costs	6.88 M DKK		- 6.88
- labour	1 persons' work	320,000 DKK	- 0.32
- grass clover consumption	38,020,833 FE	1.30 DKK pr FE	-49.43
- electricity consumption	1,186,250 kWh	0.65 DKK pr kWh	- 0.76
- water consumption	1,000 m^3	25 DKK pr m^3	- 0.03
- chemicals	25,000 DKK	25,000 DKK	- 0.03
- service and maintenance	3,038,000 DKK	3,038,000 DKK	- 3.04
- transport of slurry and residual	243,333,000 km	13.00 DKK pr km	-3.16
Local CHP plant			3.1
- consumption of biogas	10,953,418 Nm^3 natural gas	4.4 DKK pr Nm^3	- 48.20
- decreased consumption of natural gas	10,953,418 Nm^3 natural gas	1.782 DKK pr Nm^3	19.52
- biogas based power production	48,195,039 kWh	0.411 DKK pr kWh	19.81
- CO_2 tax exemption	10,953,418 Nm^3 natural gas	0.351 DKK pr Nm^3	3.84
- exemption from tax on natural gas for heat	10,953,418 Nm^3 natural gas	0.742 DKK pr Nm^3	8.13
The state			-31.78
- biogas based power production	48,195,039 kWh	0.411 DKK pr kWh	- 19.81
- CO_2 tax exemption	10,953,418 Nm^3 natural gas	0.351 DKK pr Nm^3	- 3.84
- exemption from tax on natural gas for heat	10,953,418 Nm^3 natural gas	0.742 DKK pr Nm^3	- 8.13

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

18 Biogas production from 100 % organic grass clover at a farm biogas plant with an input capacity of 50 tonnes per day plant, scenario 5C

Scenario 5C is similar to scenarios 5A and 5B in terms of the type of input used for biogas production; hence, grass clover constitutes the sole biomass input. The biogas plant is a farm plant with a daily processing capacity of 50 tonnes (18.250 tonnes per year), which is equivalent to the amount of grass clover produced on 521 ha.

As the biogas plant is a farm biogas plants, the assumptions made for scenario 5C regarding the use of the produced biogas are similar to those made in scenario 1C. Moreover, scenario 5C is similar to the other farm plant scenarios in the sense that no additional transport requirement is associated with the production.

In relation to agriculturally related effects, scenario 5C is similar to scenarios 5A and 5B, only the scale is different due to the smaller treatment capacity of the facility.

In terms of emission changes, changes are induced by the changes in energy production related to the increased production of heat and electricity from biogas and the subsequent displacement of "generic electricity" and oil based heat production.

18.1 Consequence description

Table 18.1 contains a list of all the consequences associated with scenario 5C. All the agriculturally related effects of scenario 5C are directly proportional to scenarios 5A and 5B, and therefore the relevant values are listed in the table without further specification. In other cases the situation pertaining to the farm biogas plant differs from that of the joint biogas plants and subsequently the consequences and the way to assess them also differs in some instances. Below the consequences which cannot simply be assessed by simple downscaling of the results from scenario 5A and 5B are explained in more detail.

Table 18.1 Calculated consequences of biogas production from 100 % grass clover at a farm biogas plant with a treatment capacity of 50 tonnes per day.

	Consequence per year
Economic consequences	
Agriculture – production	
- grass clover production for fodder	- 1,901,041 FE = - 9,125 tonnes
- barley production	- 455,729 kg
- triticale production	- 585,938 kg
- grass clover production for biogas production	3,802,083 FE = 18,250 tonnes
Agriculture – resource use	
- grass clover seed for fodder production	- 2,258kg
- barley seed	- 22,135 kg
- triticale seed	- 22,135 kg
- grass clover seed for biogas production	4,516 kg
- labour	- 22 hours
- fuel consumption (diesel)	- 281 litre
- electricity consumption (irrigation)	68,148 kWh
- labour (irrigation)	23,438 DKK
- machine costs (incl. irrigation)	40,620 DKK
Agriculture - yield increase	
- barley production - increased N-application	920 hkg
- triticale production - increased N-application	920 hkg
- grass clover production - increased N-application	188,902 FE
Agriculture – treated grass clover	
- reduced demand for synthetic fertilizer	79 tonnes
Transport	
- import of grass clover, barley and triticale	7,504 km
Biogas plant	
- electricity production for sale (total production)	5,705,482 kWh
- heat production – displaced gasoil	7,454,475 MJ = 207,819 litre gasoil
- investment costs	15.8 M DKK (total amount)
- labour	365 hours
- electricity consumption	119,795 kWh
- water consumption	300 m^3
- chemicals	2,500 DKK
- service and maintenance	525,000 DKK

Emission consequences (tonne)	Total	Agriculture	Transport - displaced production	Biogas
CO_2	-3,024.31	29.758	6.064	-3,060.130
N_2O	5.75	5.712	0.000	0.041
CH_4	30.53	9.337	0.000	21.191
C content of soil	130.6	130.6	0.000	
Particles	0.02	0.000	0.001	0.014
NO_x	7.95	0.018	0.045	7.890
SO_2	0.29	0.007	0.000	0.284
CO	14.83	0.005	0.007	14.816
NMVOC	0.18	0.002	0.001	0.178
N-leaching	-4.26	-4.260		

Taxes and subsidies biogas plant/On-site CHP	
- reduced demand for gas oil – energy tax	515,183
- reduced demand for gas oil - CO_2 tax	87,284

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note: Amounts stated in dkk are stated in 2009 prices.

18.1.1 Economic consequences

Biogas production per tonne of input is slightly different for the farm biogas compared to the joint biogas plants. The reason for this being that the production process is assumed to be mesophile process rather than thermophile, and that the time that the biomass is in the biogas reactor is longer (50 days compared to 20). The key factors used to calculate biogas production per tonne of input for the farm biogas plant in scenario 5C are listed in Table 18.2.

A daily biomass input of 50 tonnes is equivalent to an annual biomass input of 18,250 tonnes, and with reference to Table 18.2 where the gas production per tonne of input is seen to be equal to 71.3 Nm^3 natural gas equivalents this implies that the gross annual production of the facility amounts to approximately 1,300,00 Nm^3 natural gas equivalents. Using that the lower heating value of natural gas is 39.6 MJ per Nm^3 this is equivalent to a gross annual production of approximately 51,300,000 MJ.

Table 18.2 Calculated biogas production per tonne of input (100 % grass clover at farm biogas plant).

Dry matter (DM) content of grass clover	25 %
Kg DM pr tonne grass clover	250
VS/DM ratio [1]	0,95
Kg VS pr tonne grass clover [1]	237,5
Nm^3 CH_4 pr kg VS (HRT=50 days) [1]	0,33
Nm^3 CH_4 pr tonne grass clover	78,375
CH_4 content of biogas	60 %
Biogas production (Nm^3 pr tonne grass clover)	130,6
Heating value CH_4 (lower; MJ pr Nm^3)	35,9
Heating value Natural gas (lower; MJ pr Nm^3)	39,9
Ratio: Natural gas/CH_4	1,1
Production in natural gas equivalents (Nm^3 pr tonne grass)	71,3

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. VS means Volatile Stuff. VS/DM is the part of total dry matter which can be decomposed.

In Table 18.3 it is specified how the produced biogas is used. The process heat requirement for scenario 5C is identical to that applying to scenario 1C.

Table 18.3 Use of biogas production.

Use	Share of gross production (%)	Share in relevant energy equivalents
Gross energy production	100	1,296,701 Nm^3 Natural gas eq.
Process heat [1]	1.9	991,705 MJ
Electricity for sale [1,2]	40	5,705,482 kWh
Excess heat production [1, 3]	48.4	24,848,249 MJ

1. All heat and electricity production is assumed to be produced at a on-site CHP facility.
2. Electricity for sale is equal to gross electricity production.
3. Of the excess heat production only 30 % are assumed to be used; the remaining 70 % are assumed to be lost.

In contrast to the joint biogas plant scenarios where the biogas production in excess of what is needed to cover the process heat requirement is sold to a local CHP facility the entire biogas production is assumed to be used on the on-plant CHP for the farm biogas plants. The entire amount of electricity (5,705,482 kWh) produced at the CHP is sold. For the heat share of energy production, the heat production in excess of what is required for process heat is equal to 24,848,249 MJ. Of this excess heat production it is assumed that 30 % is put to use on the farm (e.g. for heating of stables and housing), while the remaining 70 % is lost. The 30 % of excess heat production replaces an amount of gasoil equal to 24,848,249 MJ · 0.30 : 35.87 MJ per litre = 207,819 litre gasoil

In Table 18.4 the investment costs for scenario 5C are listed. Following the approach used in the other scenarios the CHP related costs are based on a cost per MJ of 0.075 dkk. With a gross annual production of approximately 51,300,000 MJ, estimated CHP investment costs become approximately 3.8 M DKK.

Table 18.4. Calculated investment costs for farm biogas plant with a capacity of 50 tonnes per day and 100 % grass clover as input - M DKK, factor prices.

Storage facilities for grass clover	3.0
Pre-treatment of grass clover	1.0
CHP	3.8
Biogas plant	7.2
Investment costs (A1)	15.0
Projecting/planning costs (5 % of A1)	0.8
Total investment costs	15.8

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

As it appears from Table 18.1 the time required for operating the plant is set to 365 hours. In addition to this 119,795 kWh electricity is used. Water does not constitute an input to the production process as such, but water is used for cleaning of trucks, equipment etc. The annual consumption of water is estimated to be 300 m^3 water. Also different chemicals are needed with factor price value equal to 2,500 DKK. Finally annual service and maintenance costs of the biogas plant are set to 3.5 % of A1 which is equal to 525,000 DKK. The investment and operating cost calculations are based on Petersen (2010).

18.1.2 Emission consequences

The agriculturally related emissions of N_2O and CH_4 emissions from agriculture, and the changes in the C content of the soil and in N-leaching, are directly proportional to the amount of input used for biogas production. Hence, the effects pertaining to scenario 5C are equal to 1/10 of the effects pertaining to scenario 5B.

Emissions consequences related to biogas production and use

The more specific energy related emissions changes pertaining to scenario 5C are listed in Table 18.5. The assumptions underlying the calculations are similar to those applied in scenario 1C – see Section 6.1.2.

Table 18.5. Calculated emissions changes from the changes in energy production caused by the production of biogas from 100 % grass clover at a farm biogas plant with a daily input capacity of 50 tonnes - tonne.

Cause of emissions change	Base for calculation		CO_2	N_2O	CH_4	TSP	NO_x	SO_2	CO	NMVOC
	Total production	EF (g pr MJ):	0,0000	0,0016	0,4340	0,0026	0,2020	0,0192	0,3100	0,0100
Biogas based CHP-production	(51.349.341 MJ)	Change (tonne)	0,0000	0,0822	22,2856	0,1350	10,3726	0,9859	15,9183	0,5135
Reduced consumption of "generic"-	Net electricity sale from biogas plant	EF (g pr MJ):	124,7222	0,0018	0,0542	0,0042	0,1042	0,0264	0,0389	0,0111
electricity	(20.112.686 MJ)	Change (tonne)	-2.508,4989	-0,0363	-1,0894	-0,0838	-2,0951	-0,5308	-0,7822	-0,2235
	Displaced oil-based heat prodcution	EF (g pr MJ):	74,0000	0,0006	0,0007	0,0050	0,0520	0,0230	0,0430	0,0150
Reduced use of oil for heat production[1]	(7.454.475 MJ)	Change (tonne)	-551,6311	-0,0045	-0,0052	-0,0373	-0,3876	-0,1715	-0,3205	-0,1118
	Total net change inemissions (tonne):		-3.060,1301	0,0414	21,1910	0,0140	7,8899	0,2837	14,8156	0,1782

Source: Changes in emissions are calculated based on emissions coefficients from Energinet.DK (2010) (electricity), Nielsen et al. (2010) (biogas) and Danmarks Miljøundersøgelser (2011) (oil).

Note 1: It is assumed that 30 % of the excess heat production is used.

From Table 18.5 it is seen that overall the production of biogas and the associated changes in fuel use in energy production entail net increases in all emissions but CO_2.

18.1.3 Taxes and subsidies

The 20 % construction subsidy does not apply to scenario 5C due to the fact that the plant does not satisfy the requirement applying to organic based biogas plants that manure constitute minimum 50 % of the input.

As 30 % of the excess heat production at the on-site CHP displaces gasoil consumption the State will lose tax income associated with the consumption of gasoil. More specifically, the government will loose income from a gasoil tax of 2.479 DKK per litre gasoil and a CO_2 tax of 0.42 DKK per litre gasoil. The amount of gasoil displaced in scenario 5C is equal to 207,819 litre and consequently the losses in tax income are estimated to 515,183 DKK (gasoil tax) and 87,284 DKK (CO_2 tax).

The total loss in tax income incurred by the government is 602,467 DKK.

18.2 Welfare economic analysis

In Table 18.6 the welfare economic consequences associated with biogas production according to scenario 5C, their accounting prices, and their resulting welfare economic value are listed. The approaches used in the calculations are similar to those used in scenario 1A; hence, for specification of the calculation principles, reference is made to Chapter 4. Here we solely present the results.

It is seen from the table the total annual welfare economic value of biogas production according to scenario 5C is equal to – 2.09 M DKK. This means that it is a welfare economic loss for society to start this production. Of the total loss, economic consequences account for 1.5 M DKK, emissions consequences for - 0.47 M DKK and taxes and subsidies for 0.12 M DKK.

Subsidies and loss of taxes, which leads to expenditures and loss of income for the government in this case represent a welfare economic loss of 0.12 M DKK to society. This is due to the assumption that government expenditures and loss of tax income need to be financed by tax increases which are the occasion of so-called dead weight losses. If the financing problem is ignored production and use of biogas still lead to a welfare economic loss 1.97 M DKK.

The total annual reduction in greenhouse gas emissions brought about by the scenario is: (3,024.31 - 5.75*310 - 30.53 *21 + 130.6* 3.67) tonne = 1,080 tonnes CO_2 equivalents, and the value of this reduction is equal to 0.13 M DKK. If this value is subtracted from the total welfare economic costs of biogas production it is seen that it will cost society a welfare economic loss of 2.22 M DKK to obtain the indicated climate gas emission reduction. The average cost of CO_2 reduction is in this case 2,056 per tonne CO_2.

Below, the individual entries of the welfare economic account are explained.

Table 18.3 Calculated welfare economic value of biogas production from 100 % organic grass clover at a farm biogas plant with a treatment capacity of 50 tonnes per day - M DKK.

	Consequence per year	Accounting price	Welfare economic value
Economic consequences			- 1.5 M DKK
Agriculture – production			
- grass clover production for fodder	- 1,901,041 FE = - 9,125 tonnes	1.30 DKK pr FE·1.17	- 2.89 M DKK
- barley production	- 455,729 kg	1.5 DKK pr kg·1.17	- 0.80 M DKK
- triticale production	- 585,938 kg	1.6 DKK pr kg·1.17	- 1.10 M DKK
- grass clover production for biogas production	3,802,083 FE = 18,250 tonnes		
Agriculture – resource use			
- grass clover seed for fodder production	- 2,258kg	40 DKK pr kg·1.17	0.11 M DKK
- barley seed	- 22,135 kg	3.6 DKK pr kg·1.17	0.09 M DKK
- triticale seed	- 22,135 kg	3.8 DKK pr kg·1.17	0.10 M DKK
- grass clover seed for biogas production	4,516 kg	40 DKK pr kg·1.17	- 0.21 M DKK
- labour	- 22 hours	150 DKK pr hour·1.17	0.00 M DKK
- fuel consumption (diesel)	- 281 litre	3.82 DKK pr liter·1.17	0.00 M DKK
- electricity consumption (watering)	68,148 kWh	0.46 DKK pr kWh · 1.17	- 0.04 M DKK
- machine services and labour watering	23,438 DKK	23,438 DKK·1.17	- 0.03 M DKK
- maintenance of machines (incl. watering)	40,620 DKK	40,620 DKK·1.17	- 0.05 M DKK
Agriculture - yield increase			
- barley - increased N-application	920 hkg	1.5 DKK pr kg·1.17	0.16 M DKK
- triticale - increased N-application	920 hkg	1.6 DKK pr kg·1.17	0.17 M DKK
- grass clover production - increased N-application	188,902 FE	1.30 DKK pr FE·1.17	0.29 M DKK
Agriculture – treated grass clover			
- reduced demand for synthetic fertilizer	79 tonnes	7,500 DKK pr tonne · 1,17	0.69 M DKK
Transport			
- import of grass clover, barley and triticale	7,504 km	15,22 DKK pr km	- 0.11 M DKK
Biogas plant			
- electricity production for sale	5,705,482 kWh	0.46 DKK pr kWh · 1.17	3.07 M DKK
- heat production – displaced gasoil	7,454,475 MJ = 207,819 litre gasoil	110 DKK pr GJ · 1.17	0.96 M DKK
- investment costs	0.97 M DKK	0.97 M DKK · 1.17	- 1.14 M DKK
- labour	365 hours	200 DKK · 1.17	- 0.09 M DKK
- electricity consumption	119,795 kWh	0.46 DKK pr kWh · 1.17	- 0.06 M DKK
- water consumption	300 m^3	25 DKK pr m^3 · 1,17	- 0.01 M DKK
- chemicals	2,500 DKK	2,500 DKK 1.17	- 0.00 M DKK
- service and maintenance	525,000 DKK	525,000 DKK · 1.17	- 0.61 M DKK

Continued			
Emission consequences (tonne)			-0.47 M DKK
- CO_2 emissions [1]	-3,024.31 + 2,508.499	105 DKK pr tonne · 1.17	0.06 M DKK
- N_2O emissions	5.75	105 DKK pr tonne · 310 · 1.17	-0.22 M DKK
- CH_4 emissions	30.53	105 DKK pr tonne · 21 · 1.17	-0.08 M DKK
- C content of soil	130.6	105 DKK pr tonne · 3,67· 1,17	0.06 M DKK
- particle emissions	0.02		
- NO_x emissions	7.95	55,000 DKK pr tonne	-0.44 M DKK
- SO_2 emissions	0.29	85,000 DKK pr tonne	-0.02 M DKK
- CO emissions	14.83		
- NMVOC emissions	0.18		
- N-leaching	-4.26	40,000 DKK pr tonne	0.17 M DKK
Public net income	- 602,467 DKK	- 602,467 DKK · 0,2	- 0.12 M DKK
Total			- 2.09 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

Note 1. The value of CO_2 reductions from alternative electricity production due to production of electricity at the on-site CHP plant is included in the accounting price of electricity 0.46 DKK per kWh 1,17. Therefore the value of CO_2 emission consequences is calculated on the basis the total CO_2 consequences 3,024.31tonnes deducted reduced CO_2 emissions from alternative electricity production 2,508.499 tonnes.

18.2.1 Value of economic consequences

Generally accounting prices of economic consequences are determined as for scenario 1A – cf. Section 4.2.1 – and scenario 1C (gasoil) – cf. Section 6.2.1.

18.2.2 Value of emission consequences

With regard to determination of accounting prices for emission consequences refer to Section 4.2.2.

18.2.3 Public net income – tax distortion loss

In Section 18.1.3 it was calculated that the public sector will loose annual tax income equal to 602,467 DKK. The welfare economic value of this loss is calculated by multiplying it with the so called tax distortion factor equal to 0.2 to get the annual tax distortion loss of 0.12 M DKK.

18.3 Financial analysis

In Table 18.7 the results of the financial analysis pertaining to scenario 5C are presented. Reference is made to Section 4.3 and 6.3 for more detailed descriptions of the principles applied in the calculations.

Table 18.7 Calculated financial consequences of biogas production from 100 % grass clover at a farm biogas plant with a treatment capacity of 50 tonnes per day - M DKK.

	Consequence per year	Price	Income and expenditures
Agriculture			1.86 M DKK
Production			
- grass clover for fodder	- 1,901,041 FE	1.30 DKK pr FE	-2.47 M DKK
- barley	- 455,729 kg	1.5 DKK pr kg	-0.68 M DKK
- triticale	- 585,938 kg	1.6 DKK pr kg	-0.94 M DKK
- grass clover for biogas production	3,802,083 FE	1.30 DKK pr FE	4.94 M DKK
Resource use			
- grass clover seed for fodder production	- 2,258kg	40 DKK pr kg	0.09 M DKK
- barley seed	- 22,135 kg	3.6 DKK pr kg	0.08 M DKK
- triticale seed	- 22,135 kg	3.8 DKK pr kg	0.08 M DKK
- grass clover seed for biogas production	4,516 kg	40 DKK pr kg	-0.18 M DKK
- labour	- 22 hours	150 DKK pr hour	0.00 M DKK
- fuel consumption (diesel)	- 281 litre	4.3 DKK pr liter	0.00 M DKK
- electricity consumption (watering)	68,148 kWh	0.45 DKK pr kWh	-0.03 M DKK
- machine services and labour watering	23,438 DKK		-0.02 M DKK
- maintenance of machines (incl. watering)	40,620 DKK		-0.04 M DKK
- import grass clover, barley, triticale – transport	7,504 km	13.00 DKK pr km	-0.10 M DKK
Agriculture - yield increase			
- barley - increased N-application	920 hkg	1.5 DKK pr kg	0.14 M DKK
- triticale - increased N-application	920 hkg	1.6 DKK pr kg	0.15 M DKK
- grass clover production - increased N-application	188,902 FE	1.30 DKK pr FE	0.25 M DKK
Fertilizer effect of treated grass clover			
- demand for synthetic fertilizer	- 79 tonnes	7,500 DKK pr tonne	0.59 M DKK
Biogas plant			-0.98 M DKK
- electricity production for sale	5,705,482 kWh	0.772 DKK pr kWh	4.40 M DKK
- heat production – displaced gasoil	7,454,475 MJ = 207,819 litre gasoil	6.845 DKK pr litre	1.42 M DKK
- investment costs	- 1.17 M DKK		- 1.17 M DKK
- labour	365 hours	200 DKK	- 0.07 M DKK
- grass clover consumption	3,802,083	1.30 DKK pr FE	-4.94 M DKK
- electricity consumption	119,795 kWh	0.65 DKK pr kWh	- 0.08 M DKK
- water consumption	300 m^3	25 DKK pr m^3	- 0.01 M DKK
- chemicals	2,500 DKK	25,000 DKK	- 0.00 M DKK
- service and maintenance	525,000 DKK	469,000 DKK	- 0.53 M DKK
The state			- 0.61 M DKK
- reduced demand for gas oil – energy tax	515,183 DKK		- 0.52 M DKK
- reduced demand for gas oil - CO_2 tax	87,284 DKK		- 0,09 M DKK

Sources: Own calculations based on data from the BIOMAN partners and data from the sources mentioned in the chapter.

19 Discussion of results

The present report presents the results of welfare as well as financial economic analyses of biogas production based on 5 different types of biomass inputs. The analyses for each type of input are conducted for three different plant sizes.

19.1 The context of the analyses

The results of the analyses may be interpreted in the political context where Denmark has committed it self to a number of targets regarding GHG reduction and renewable energy shares. The production of biogas contributes to the fulfilment of both these targets. Seen from a welfare economic point of view, however, it is not just important that the targets are met; it is also important that the targets are reached with the lowest possible level of welfare economic loss. In order to ensure that this is the case it is important that the welfare economic costs associated with the different possible biogas production approaches are compared with the costs associated with reaching the set targets by alternative means, e.g. technologies or regulatory measures.

19.1.1 The scenarios

It is by no means to be expected that the production approaches considered here will be relevant for inclusion in an optimal national energy plan that ensures the joint production of energy and attainment of GHG and renewable energy targets at the lowest possible welfare economic costs. Hence, as described in chapter 1 the scenarios have not been defined with cost-efficiency in mind. In stead, the intention has been to assess the economic consequences of a number of scenarios, which do not include industrial waste, since this has become a short-supply good. Until quite recently the addition of such waste with a high energy content has ensured the profitability of biogas production, but in relation to the future anticipated expansion of biogas production this is no longer a relevant opportunity. Consequently alternative production approaches need to be adopted, and in this context the purpose of the present study has been to assess the economic consequences of biogas production based solely on slurry and/or plant material, thereby shedding light on the economic relevance of such approaches. Stated differently, the purpose of the analyses has accordingly not been to identify the optimal approach to biogas production, i.e. the production approach which is welfare economically efficient. This fact is important to bear in mind when interpreting the results of the analyses. Hence, the results should not be interpreted as evidence for the general desirability or undesirability of biogas production as such, but rather as economic assessments of the welfare economic and financial economic consequences of different possible production approaches, which may or may not be relevant in connection with the anticipated future expansion of biogas production where the addition of high energy waste will not be an option.

In relation to the scenarios involving slurry as an input it may be noted that the results are affected by the low dry matter content of slurry assumed in the present analyses. If comparing the results to the results of other studies this should be borne in mind since increasing the dry matter content from the practice based level to e.g. the norm based level would have a significant impact on the gas production and there by also on the results. In this connetion it is important to note that increasing the dry matter content of slurry would lead to proportional increases in the amount of biogas produced which would be tantamount to increases in the benefits brought about by biogas production. In contrast it would basically have no implications in relation to the direct economic costs associated with biogas production. In relation to emissions changes, increasing the dry matter content of slurry would entail further decreases in the C-content of the soil, in N_2O emissions and in total GHG emissions from the energy sector – i.e. there will be costs as well as benefits when it comes to the value of emissions changes. Overall, however, there seems to be no doubt that significant economic gains could be realised if it is possible to obtain higher dry matter contents for slurry than the ones assumed in the present analyses. Dertermining whether or not the potential gains would be sufficiently large to make biogas production welfare economically favourable requires new analyses and such analyses has not been possible within the limits of the present project.

In relation to whether it in practice is realistic to obtain a higher dry matter content of slurry than the one used in the present analyses it may be noted that significant improvements, e.g. to the norm based level, may not be unrealistic. An increased dry matter content can either be obtained though the adoption of technical solutions such as slurry seperation technologies or through changes livestock management practices (e.g. reduced water use). Seen from a economic perspective the latter of these options are likely to be the most relevant, as it is not necessarily associated with increased costs. In fact, optimising water use and feeding plans may even in the long run have the potential to increase the profitability of livestock production. In contrast, the implementation of technologies such as e.g. seperation increases the costs of production. Currently there appears to be no definite answer to the question of whether or not the benefits from higher dry matter content exceed the costs of seperation; hence, seperation does not seem to be the panacea to the economic challenges facing slurry based biogas production. All in all, it seems reasonable to assume that if not now, then at least within the forseeable future, it should be realistic to obtain higher (and perhaps significantly higher) slurry dry matter contents than the ones used in the present analyses. Seen from this perspective, there is reason to expect that the results of the present analyses represent lower bound estimates of the welfare economic value of biogas production.

19.1.2 The welfare economic analyses

The welfare economic analyses are conducted to illustrate the advantages and disadvantages associated with the chosen biogas scenarios seen from society's point of view. As far as it has been possible the welfare economic value of all relevant resource- and environmental consequences has been accounted for in the analyses, thereby facilitating the estimation of an aggregate estimate of the total effect which the scenarios will have on the over all level of welfare in society. The welfare economic analyses also include an assessment of the welfare economic GHG reduction cost implied by each scenario; the GHG reduction cost is measured in terms of the cost in DKK. per tonne of GHG reduction measured in CO_2 equivalents. This unit cost estimate is relevant in relation to compare the cost-effectiveness of GHG reductions across alternative GHG reduction measures.

Considering that the biogas production approaches considered in the present analysis do not necessarily represent optimal production approaches it is not surprising that the resulting GHG reduction costs are quite high compared to the results obtained in other studies. Discrepancies between the results of the present study and the results of other studies may also be the results of differences in underlying assumptions, e.g. assumptions regarding transportation demand, transportation costs, accounting prices and the treatment of the tax distortion loss. In this connection it may also be noted that uncertainties regarding investment and operating costs may play an important role; hence, these are likely to be very dependent on the specific circumstances in a given case, and therefore they are difficult to estimate on such a general level as done here. In many cases it will probably be possible to obtain significant cost reductions compared to the estimates used here, while in others costs will be higher. Hence, the estimates used here are intended to reflect average costs, but it should be noted that in reality costs are likely to span a quite wide interval.

GHG reduction costs

In relation to GHG reductions and the welfare economic analyses it may be noted that the welfare economic analyses are based on a CO_2 quota price of 105 DKK per tonne. That is, the reductions in GHG emissions which the scenarios give rise to are valued according to this price. Hence, the over all welfare economic results of the scenarios would be improved if a higher quota price was assumed. The estimated GHG reduction costs associated with the scenarios, however, are not affected by the assumed value of GHG reductions. Hence, the GHG reduction costs reflect the implied costs of GHG reductions and can therefore be interpreted as a estimate of how high the CO_2 quota price (which ideally should reflect the marginal cost of GHG abatement across all sectors) should be for the considered reduction approach to be desirable seen from a welfare economic point of view. Considering that reality is less than ideal, e.g. due to the setting of several mutually interrelated goals and the implementation of different regulatory measures across sectors, it is not realistic to expect that marginal abatement costs will be identical across all sectors, and consequently it may be considered welfare economically relevant to engage in biogas production despite implied GHG reduction costs being larger than the CO_2 quota price.

19.1.3 The financial economic analyses

The financial economic analyses are conducted with the purpose of illustrating the economic consequences for the involved enterprises and the State. The results of the analyses are very dependent on the underlying assumptions regarding who bears the costs for what and the prices at which products are traded. To some extent the results are therefore primarily illustrative in the sense that they provide a base for evaluating whether or not the economic incentives facing the different involved business are sufficient for the given production to be initiated. Also, they may be used to illustrate the extent to which a redistribution of costs and benefits can create the necessary incentives for all relevant businesses and the extent to which agreements on such redistributions are likely to be achievable. Moreover, if the given production approach is considered welfare economically desirable, e.g. based on joint consideration of the different targets set within the energy sector, the results of the financial analyses can also be used as a base for political interventions in relation to the price, tax and/or subsidy structure focussed on making the production attractive for all the involved businesses.

The present chapter contains a discussion of the results of the welfare economic and financial economic analyses presented in chapters 4-18. It is also discussed if the results of these analyses should have any implications for the prices of biomass, payment of transport costs, the price of biogas and for present biogas dependent taxes and subsidies. Finally the results of sensitivity analyses with regard to assumed climate gas emission coefficients and transport costs are presented.

19.2 The welfare economic results

Common for all the considered biogas production scenarios is that they result in a welfare economic loss. This holds good even if the welfare economic loss due the tax distortion loss resulting from increased net expenses for the State is ignored. This suggests that biogas production does not represent a desirable activity seen from society's point of view. Despite the fact that this conclusion applies to all scenarios independent of plant capacity and type of input the results also show that there are differences between scenarios in terms of their relative desirability.

19.2.1 GHG reduction costs

Table 19.1 lists the total GHG reduction and the total welfare costs for each of the scenarios. It is seen that the GHG reduction potential in all scenarios as expected depends on the size of the biogas plant and that scenario 4A has the highest potential. Total welfare economic costs also depend on the assumed plant size and it is scenario 5A which gives rise to the highest costs.

Due to different outcomes across scenarios in terms of net GHG effect it does not make sense to compare the absolute welfare economic values of the different scenarios. In stead comparisons across scenarios need to be based on a relative measure, e.g. the average costs per unit of GHG reductions. This measure is also listed in Table 19.1 and it is seen that the welfare economic costs of GHG reductions varies significantly across scenarios. Scenario 3A has the lowest costs of 509 DKK per tonne CO_2 equivalent while scenario 5A has the highest costs of 3,268 DKK per CO_2 equivalent.

Table 19.1 Welfare economic costs of biogas production for the analysed scenarios.

Scenarie	Total GHG reduction (tonne)	Total costs (M DKK)	DKK pr tonne CO_2 equivalent reduction
1A	10,367	6.45	745
1B	6,529	3.91	721
1C	676	0.43	754
2A	16,084	20.38	1,390
2B	10,115	11.31	1,241
2C	1,012	0.8	909
3A	14,906	5.76	509
3B	9,367	4.1	560
3C	952	0.38	525
4A	18,768	30.41	1,743
4B	11,803	18.54	1,694
4C	1,213	1.26	1,162
5A	16,320	51.33	3,268
5B	10,297	32.33	3,263
5C	1,080	2.09	2,056

19.2.2 Plant size

Looking at differences across different plant sizes in relation to GHG reduction costs it appears that the farm biogas plants generally give rise to the lowest costs, while the costs for the joint plants seem to be fairly stable across the two different plant sizes. With reference to economics of scale these results are somewhat surprising; however, with reference to the assumptions underlying the analyses the results can be explained.

Joint biogas plants

Starting with the joint biogas plants one would – all else equal – expect average reduction costs to be decreasing with increasing plant size, and therefore the seemingly lack of significant differences between the costs applying to the 500 and 800 tonnes per day plants is counterintuitive. An important explanation for the results is that it based on the available data has been difficult to properly reflect the economics of scale element; that is, due to lack of detailed data on e.g. the relationship between plant size and investment and operating costs it has been difficult to properly incorporate the scale aspect in the analyses. Consequently it must be emphasised that the lack of significant differences in the result pertaining to the joint plants for a given input type should not be interpreted as evidence against the economics of scale theory; instead it should be seen as a result of insufficient data, and perhaps as an indication of the level of uncertainty which analyses conducted at such a general level as the present ones are subjected to.

Farm biogas plants

Turning to the differences in GHG reduction costs between the farm plants and the joint plants an important explanation for the also somewhat counterintuitive result is likely to be the fact that the biogas plant in the farm scenarios are located on the farm implying that there is no increased demand for transport associated with transporting biomass to and from the biogas plant. Still, however, it is quite interesting that the costs applying to the farm scenarios are so relatively low. Hence, with reference to the fact that the analyses are based on the assumption that only 30 % of the excess heat production is actually put to use, while the remaining 70 % is lost, one might have anticipated significantly higher costs for the farm plants compared to the joint plants. In this connection it should be noted that GHG reduction costs for the farm scenarios could be reduced significantly if the degree of heat utilization could be increased; this would not only increase the benefit from reduced consumption of gasoil, it would also increase the total amount of GHG reduction. It is however important to note that the background for assuming a heat utilization rate of 30 % is that it in most cases is considered unlikely that significantly higher rates of heat utilization can be obtained without significant costs. Hence it is important to weigh the costs associated with using the heat, e.g. costs for establishing heat pipelines, against the benefits obtained by increasing the rate of heat utilization. Therefore it will probably only be a realistic option in cases where the biogas plant can be located very close to potential buyers, e.g. small rural communities, and such locations may be difficult to find considering that such a solution might be considered undesirable because of e.g. smell problems.

19.2.3 Input type

Looking at differences in GHG reduction costs across the different input types it is seen that costs increase with increasing share of plant input. Considering that the gas production per tonne of input is significantly higher for plant material than for slurry, this result may seem counterintuitive. However, the result follows from the fact that the used plant material is agricultural crops which are associated with high opportunity costs. Hence, although the effect of adding plant material is to increase biogas production the value of the increased production is not sufficiently high to compensate for the value of lost plant materials for feed. In this connection it may be noted that the results perhaps would have looked markedly different if a different kind of plant material, e.g. one with zero or at least significantly lower opportunity costs had been used as input. In future analyses it could therefore be interesting to look at plant material that has no real alternative use and/or is grown on areas where no alternative production is displaced. Such plant material and areas might be grass from nature preservation areas, but whether this will in fact be a viable production approach depends on the gas production potential of such crops. Finally, in relation to the important role played by the opportunity costs of plant biomass it may be noted that the overall results of course would be improved if lower opportunity costs are assumed.

In terms of input related assumptions it may also be noted that, the fact that the analyses are based on a low dry matter content for slurry (i.e. the dry matter content resulting from current agricultural practice in stead of e.g. the norm based dry matter content) has important implications in relation to the results. Thus, as discussed in Section 19.1.1 the economic results would have been significantly better if the dry matter content of slurry has been set higher in the analyses.

19.2.4 Energy related assumptions

In the analyses concerning the joint biogas plants the welfare economic value of the produced biogas is assessed with reference to the price on natural gas. This implies that the value of the biogas will increase if the price on natural gas increases, and vice versa. Therefore a higher price of natural gas will – all other prices being unchanged – make biogas production more welfare economical profitable to society. Also a higher CO_2 accounting price – i.e. the international price of CO_2 permits – will of course make biogas production more welfare economical favourable to society.

The analyses are also based on the assumption that all the produced electricity and heat is put to use, i.e. that it displace alternative heat and electricity production. Whether or not this is a reasonable approach to assess the welfare economic value of biogas can be discussed. Hence, with reference to the discussion in chapter 1 on inflexibility of biogas compared to natural gas in relation to adjustment of CHP production according to seasonal fluctuations in demand for heat it could be argued that biogas should be assigned a lower value than that suggested by it's natural gas equivalent value. If this is considered a more reasonable approach, it should be noted that the GHG reduction costs estimated for all scenarios would increase. Also, in the case that not all the produced heat is put to use, then the resulting level of GHG reductions will be reduced, and this will also serve to increase the resulting GHG reduction costs.

Biogas production – and thereby the value of the biogas – is affected by two kinds of inflexibilities; inflexibility in terms of market possibilities and inflexibility in terms of adjusting production. An often mentioned possibility to ameliorate these problems is to upgrade the biogas and subsequently feed it into the natural gas distribution network. However, until recently there has not been much focus on this possibility both due to the costs associated with the upgrading process and due to the current tax structure which only favours biogas when used for CHP production. According to Skøtt (2011b) it is however possible to upgrade biogas for costs as low as 50 DKK per Nm^3 CH_4. This suggests that it may become a relevant option in the very near future – and particularly so when seen in the context of the political focus on expanding biogas production significantly within a very short time period. Hence, in such a situation it is likely to be increasingly important to ensure flexibility within the energy producing sector, and perhaps therefore the creation of equal tax and subsidy terms for biogas independent of end use is high on the political agenda in relation to improving the role played by agriculture as a supplier of green energy (Regeringen, 2009).

19.2.5 Organic agriculture

Three of the input compositions considered in the present analyses originate from organic agriculture. The reason for this being, that biogas production is suggested to be particularly interesting seen from the perspective of organic agriculture where fertiliser is in limited supply and yield therefore may be restricted by the level of N-available. Seen from this perspective an important advantage of biogas production is the high fertiliser value of the treated biomass. Hence biogas production based on organic inputs opens up the possibility that organic agriculture no longer has to rely on the import of slurry from conventional agriculture and perhaps also that the overall level of N-application (and thereby also yield) can be increased. In the organic scenarios involving grass clover – either 50 % or 100 % - it is seen that the agricultural benefits related to the fertilizer value of the treated biomass (scenarios 4 and 5) and the benefits from increased N-application (scenarios 5) are seen to be quite large. In total, seen from a welfare economic point of view, biogas production based on grass clover as a significant proportion of the input is nevertheless not desirable and the implied GHG reduction costs are also quite large. This is primarily due to the high opportunity costs of using grass clover for biogas production instead of feed, high transportation costs and a big tax distortion loss related to high net expenses for the State.

19.3 The financial economic results

Table 19.2 presents the results of the financial economic analyses of each of the scenarios. Here is seen that in general the results are quite similar across input types and plant size. Hence, in all cases considered biogas production will be profitable for agriculture and the local CHP plant, while it in all cases will inflict looses on the State. Moreover, in all cases but two, biogas production will also be unprofitable for the biogas plant. As mentioned several times in chapters 4 through 18, the results of the financial analyses are to a great extent the results of the assumptions on which the analyses are based. As an example the economic surplus accruing to agriculture would have been significantly smaller had it been assumed that it was the farmers who had to pay for the transport of the input material, and equivalently the economic loss experienced by the biogas plant would have been smaller or perhaps even positive – and for the scenarios involving plant material the same would be the case if a lower price of maize and grass clover was assumed.

19.3.1 Distribution of costs

In reality, it seems fair to expect that it in particular cases may be possible for the different private actors to reach agreements which ensure a more equal distribution of costs across actors. No doubt agriculture or the local CHP plant will not on their own accord suggest to cover more costs than necessary, but in the case that the construction of a biogas plant is contingent upon their agreement to some level of cost sharing it will be irrational of them not to accept this provided that their own financial outcome remains positive. Hence, in many cases – and even the scenarios involving grass clover – it would probably be possible to devise arrangements ensuring that biogas production will be economically profitable for agriculture, the biogas plant and the local CHP. In particular, one might expect negotiations to be centred on the price by which plant material is traded, who pays for the transport of input and the price paid for biogas. In connection with the price which the local CHP are assumed to pay for biogas in the analyses it may be noted that the price is lower than the break-even price between natural gas and biogas. The break even price is the price that the local CHP should be willing to pay for biogas taken into account the relative methane content of biogas and natural gas and the tax and subsidy advantages of using biogas instead of natural gas – i.e. for a given natural gas price, the biogas price at which the financial economic result of the local CHP is the same irrespective of natural gas or biogas being used at fuel..The difference between the assumed price and the break-even price is intended to reflect the comparative disadvantages of biogas compared to natural gas in terms of flexibility, and due to this inflexibility it does not seem reasonable to assume that the CHP would be willing to pay the break-even price. However, it may be the case that they will be willing to pay a higher price than the one assumed here.

Independent of potential cost sharing agreements which may be reached among agriculture, the biogas plant and the local CHP the results suggests that biogas production seen from the point of view of the state under all circumstances will give rise to a significant financial loss. The reason for the loss being increased costs for subsidies and reduced revenue from taxes. This, however, may be acceptable, depending on the weight attached to obtaining the goals set in terms of renewable energy in general, biogas production in particular and GHG reduction, and on the costs associated with the alternative ways to meet these goals. In this connection it may be noted that the financial loss inflicted on the state would be reduced if biogas – under the current tax/subsidy structure – is upgraded and feed into the natural gas system. However, this scenario is unlikely, as a prerequisite for this approach to be attractive seen from an economic point of view is that the tax/subsidy structure is changes, and in case this happens, the loss inflicted on the state will prevail.

For the farm biogas plants one might say that agriculture and biogas plant are in fact the same actor. As the biogas plant is located on the farm it seems reasonable to assume that the owner in practice is the same person, although it may officially be run as two separate businesses. If the results for agriculture and the biogas plant are added for the farm plants it is seen that biogas production in all cases except scenario 1C actually leads to a positive financial result. Hence, in these cases the state is the only one who is inflicted with a financial loss. In connection with the negative result for scenario 1C it may be noted that this is partly due to the lack of investment subsidy in this scenario. Hence, had farm biogas plants based on input from conventional agriculture qualified for the investment subsidy then the results for this scenario would also have been positive. Moreover, it may be noted that the economic profitability of biogas production at the farm plants would be significantly improved if a higher degree of heat utilization could be obtained. However, as discussed in the previous section it seem unlikely that it can be increased significantly, and obtaining a higher degree of energy efficiency from farm level plants would most likely require that the biogas is sold to a local CHP or upgraded. The problems associated with the latter of these options have already been discussed, and in relation to the former an important obstacle is the cost associated with transporting the biogas from the biogas plant to the CHP plant.

19.3.2 Organic agriculture

Finally, looking specifically at the results for the organic scenarios, and particularly the scenarios involving grass clover (scenarios 4 and 5) it is seen that biogas production may in fact contribute to increasing the profitability of organic agriculture significantly. Hence seen from a financial economic point of view expansion of organically based biogas production seems to make good sense for the agricultural sector. In this connection it should however be noted that initiation of biogas production based on grass clover requires that agriculture agrees to engage in some kind of cost sharing with the biogas plant - otherwise it will not be an attractive production activity seen from the biogas plant point of view.

Table 19.2 Results of the financial analyses (M DKK).

Scenarie	Agriculture	Biogas plant	Local CHP plant	The state
1A	0.86	-1.77	0.38	-4.94
1B	0.54	-0.96	0.24	-3.21
1C	0.05	-0.28	0	-0.06
2A	7.31	-1.03	1.85	-20.19
2B	4.55	-0.47	1.15	-12.75
2C	0.45	-0.15	0	-0.23
3A	1.72	0.28	0.51	-6.28
3B	1.07	0.33	0.3	-4.04
3C	0.1	-0.05	0	-0.2
4A	13.91	-9.46	2.74	-29.53
4B	8.69	-5.52	1.71	-18.6
4C	0.86	-0.4	0	-0.52
5A	29.76	-20.76	4.96	-50.84
5B	18.59	-12.61	3.1	-31.78
5C	1.86	-0.98	0	-0.61

19.4 Subsidies and taxes – regulatory implications and perspectives

The political community advocates a significant expansion of biogas production in Denmark. As an example the former Government has recently suggested a potential increase in the price subsidy and investment subsidy granted to biogas and biogas plants. No doubt this will improve the economic incentives for private actors to engage in the production of biogas, thereby contributing to the desired expansion of the sector and to the attainment of the underlying targets set in terms of GHG reductions and share of renewable energy. However, the questions are whether such an expansion of biogas production is desirable seen from a welfare economic point of view, and if such general subsidization of biogas production constitute an appropriate regulatory framework for the sector

The results of the welfare economic analyses included in the present report reveals that biogas production in all the cases considered give rise to welfare economic losses. The financial economic analyses on the other hand show that while biogas production according to the described scenarios is likely to be economically profitable for the agricultural sector and local CHP plants it is likely to result in net- losses for the biogas plant as well as the state. Hence, seen from a financial economic point of view, the economic desirability of biogas production varies significantly across different actors. In relation to the interpretation of the results it is important to emphasise that the results are inextricably linked to the underlying assumptions, and if these are changed the results will also change. Consequently the results cannot be used as the base for drawing more general level conclusions regarding the welfare economic desirability of biogas production. Having said this, the calculations in the present report has shown quite clearly that the welfare economic GHG reduction costs associated with biogas production can be quite high, and in some instances very high. Hence, different approaches to biogas production are not equally desirable, implying that it matters which approach one chooses to follow. In relation to the fulfilment of the energy and climate related goals set in terms of GHG reduction and shares of renewable energy in energy production, this underlines the importance of comparing the costs associated with biogas production with the costs associated with alternative approaches to meet the goal. Hence, seen from a rational economic point of view it should be the welfare economic cost effectiveness of different technologies and regulatory measures that determines the composition of the country's climate and energy policy.

In relation to the presence of several co-existing targets it is however important to note that the marginal welfare economic costs associated with meeting the different political targets can be very different. Hence it is possible that the least cost way to meet the GHG reduction target fails to entail the simultaneous fulfilment of the renewable energy target. Consequently fulfilment of both targets may require the inclusion of less cost effective measures in the portfolio of measures.

Seen from a policy point of view the results serve to illustrate the potential inefficiencies introduced by implementing general tax and subsidy structures favouring biogas production. Hence, the results of the analyses shows how tax exemptions and subsidies contributes to making welfare economically undesirable production approaches financially attractive for private actors. Seen from this perspective, the analysis highlights the importance of targeting policies and designing regulatory instruments in a way that ensures that private actors are provided with incentives to engage in welfare economically desirable biogas production activities and discouraged from engaging in welfare economically undesirable activities. Hence, tax exemptions and subsidies should therefore be targeted at the production approaches deemed most desirable seen from a welfare economic point of view – e.g. in terms of the implied GHG reduction cost. Maybe this way of thinking is not completely absent in current legislation; as an example, the 20 % construction subsidy does not apply to biogas production based on 100 % plant material. Hence, an explanation for this may be the fact that such production is considered undesirable – and this is supported by the results of the present analysis where the welfare economic cost of biogas production is shown to increase with increased plant share of input. However, despite the fact that current legislation at least to some extent seem to reflect the fact that biogas production consitute a broad range of different approaches of which some may be welfare economically desirable while others may not, the results of the analyses quite clearly suggest that there is a need to refine the design of regulatory initiatives in order to make sure that the correct incentives result. Hence, the fact the analyses have shown that production approaches resulting in welfare economic losses are rendered financial economic profitable suggest thare is room for improvement.

In terms of the effect of tax exemptions and subsidies it may be noted that they have the opposite effect on the results of the welfare economic analyses and the financial analyses. While tax exemptions and subsidies serves to increase the earning of the businesses involved in biogas production thereby making biogas production more attractive they simultaneously lead to an increase in the welfare economic cost of biogas production. This is caused by the fact that increased tax exemptions and subsidies entail an increase in expenses (or: decreased revenues) for the State. Provided that this increase in expenses needs to be financed through higher taxes, this gives rise to a tax distortion loss, which increases the welfare economic loss associated with biogas production.

Following up on the discussion in Section 19.1. on the possibility of upgrading biogas and feeding it into the natural gas network it is important to note that this option although technically feasible is unlikely to be seen in practice. This is due to the tax and subsidy structure which favours biogas used for CHP production while treating upgraded biogas on equal terms with natural gas. Hence, for this approach to be economically attractive to private enterprises, it is a prerequisite, that the tax and/or subsidy structure is modified so that comparative advantages of biogas compared to natural gas are reflected in the value assigned to biogas on the market independent of the end use. In this connection it is worth noting that the creation of equal tax and subsidy structures for biogas used for CHP production and biogas fed into the natural gas network is included in the agreement on "green growth" issued by the government in June 2009 (Regeringen, 2009). Whether this initiative can be regarded as a welfare economic advantage can be discussed, but it is always important to be aware of the consequences of treating the same good differently dependent on the context; and in the context of biogas production and use there seems to be a risk that it is inefficient.

19.5 Biogas and GHG reduction costs – sensitivity of results

Biogas represents a renewable source of energy and in this connection increasing the production of biogas has the potential to contribute to the reduction of GHG emissions – an issue which is high on the national agenda. As shown in the analyses all the considered scenarios lead to GHG reductions, but all scenarios are also shown to lead to welfare economic losses. Hence, the reductions come at cost. As shown in table 19.1 the costs of GHG reductions per CO_2 equivalent implied by the scenarios varies from app. 500 to app. 3,500 DKK per tonne CO_2 equivalent.

However, considering the political goals set in terms of GHG reductions and the share of renewable energy of total energy production biogas production it may be a welfare economic relevant energy production approach despite the apparent welfare economic loss it gives rise to,. Whether this will be the case depends on the relative cost of obtaining GHG emissions reductions through biogas production compared to the costs of obtaining the reductions by use of other renewable energy sources. In this connection the costs per CO_2 equivalent reduction implied by the scenarios play an important role, as this represents an important base for comparing different GHG reduction initiatives. Seen from this perspective it is therefore considered relevant to investigate the sensitivity of the results regarding cost effectiveness of GHG reductions to changes in the assumptions underlying the calculations of GHG reductions for the scenarios.

The costs of GHG reductions are calculated by dividing the welfare economic net costs of the scenario (excluding the value of GHG reductions) by the change in GHG emissions induced by the scenario. The sensitivity analyses will be focused on the implications of uncertainty in relation to the emissions coefficients used to calculate changes in GHG emissions for the scenarios. More specifically, one part of the sensitivity analyses will be focussed on the sensitivity of the results to changes in the emissions coefficients used in the assessment of changes in N_2O emissions, CH_4 emissions and changes in the C-content of the soil – i.e. the agriculturally and biogas production related emission changes induced by biogas production. In addition to this, the sensitivity of the results for the 800 tonnes per day biogas plants to a reduction in the demand for transport of the inputs to biogas production is also investigated.

Certainly it could also be relevant to conduct sensitivity analyses with respect to other variables, e.g. gas production per tonne of input, the price of natural gas or the opportunity costs associated with withdrawing land from agricultural production. However, within the resource confines of the present project it has not been possible to conduce such analyses, but there remains no doubt that applying a higher estimate of the gas production per tonne of input or lowering the price attached to the displaced agricultural production could improve both the welfare economic and the financial results significantly, just as applying a higher natural price could improve the welfare economic results significantly.

19.5.1 Sensitivity to changes in emissions coefficients

The emissions coefficients used to calculate the agriculturally and biogas related changes in GHG emissions in the present analyses are determined by experts within the field. Despite this, however, emission changes may be associated with significant uncertainties – both due to case specific factors and more general uncertainties related to difficulties associated with determining the relevant factors exactly. In the sensitivity analyses conducted here, the emissions coefficients for the 3 considered GHG emissions sources are set to a minimum value and a maximum value. Subsequently, the effect of changing the emissions factors is estimated one at a time, thereby assessing the isolated effect of changing that emission factor from its base level to either the minimum or maximum value. The effect is evaluated in terms of the effect it has on the average costs of GHG reductions. In relation to the approach adopted in the sensitivity analyses it should be noted that it could be equally relevant to investigate the joint effects of varying several factors simultaneously. Seen from a practical point of view, however, this is not a feasible approach since it would result in too many scenarios to analyse.

N_2O emissions

In relation to the calculation of changes in N_2O emissions, the sensitivity analyses are solely focused on the emissions of N_2O from the biomass used for biogas production. Specific emissions coefficients apply to each scenario as described in chapters 4, 7, 10, 13 and 16. In the sensitivity analyses the emissions factors for the biogas scenario are set to 0.5 and 1.5 times the emission factor used in the analyses thereby facilitating the estimation of a minimum and maximum value for changes in N_2O emissions. It should be noted, that it is the emissions coefficients for the biogas scenarios that are varied while the emissions coefficients for the reference scenario without biogas production are kept constant.

The effects on the estimated costs of GHG reductions of changing the N_2O emissions coefficients to the minimum and maximum value are shown in table 19.3. As it is seen in the table, varying the N_2O emission factor by a factor 0.5 or 1.5 significantly changes the results in terms of the estimated GHG reduction costs. Not surprisingly, the effect is proportional across plant sizes for a given input type; this follows from the fact that N_2O emissions are directly proportional to the amount of input used for biogas production. Comparing effects across different input types, it is seen that the sensitivity of the results increases as the plant material share of input increases. Hence, using plant material for biogas production is associated with large changes in N_2O emissions; i.e. where N_2O emissions from plant material in the reference situation only pertained to emissions from crop residues, N_2O emissions in the biogas scenario are calculated based on the N-content of the total amount of plant material. This implies that the total amount of N which constitute the base for calculating N_2O emissions is much larger in the scenarios involving plant material then in the ones where slurry constitute the sole input. Comparing the results for e.g. scenario 2A, 4A and 5A illustrates the relationship between plant share of input and sensitivity of results to changes in the applied N_2O emissions coefficients, and in this connection it is worth noting that N_2O emissions actually increase for the scenarios based on 100 % grass clover if the emissions coefficient for N_2O is increased to 1.5 times the base level. In fact the increase in N_2O emissions is so high that it leads to an increase in the overall level of GHG emissions rather than a decrease – a quite perverse situation considering that GHG abatement seems to be one of the most important driving forces behind the target of increasing biogas production.

CH_4 emissions

In relation to the calculation of changes in CH_4 emissions, the sensitivity analyses are focused on CH_4 emissions from the plant material used as input to biogas production. Hence, the sensitivity analyses are only relevant for the scenarios involving plant material as input. In the analyses of the scenarios CH_4 emissions from plant material are assumed to be equal to 1 % of the total CH_4 production originating from the plant material. In the sensitivity analyses the minimum value is set to 0 % while the maximum value is set to 3 %.

The effects on the estimated price of GHG reductions of changing the emission coefficient for CH_4 to the minimum and maximum value are shown in Table 19.3. In terms of the effects on the estimated GHG reduction costs of changing the emissions coefficient for CH_4 emissions it is seen that results are less sensitive to changes in the assumptions regarding CH_4 emissions than to changes in the assumptions regarding N_2O emission. Once again the level of sensitivity displayed across input types reveals that sensitivity increases with increased plant share of input; however, this follows from the fact that CH_4 emissions only are calculated based on the biogas production originating from the plant share of input. Although there does not appear to be any difference in sensitivity across plant sizes, the GHG cost estimates pertaining to the farm biogas plants ought to be a bit more sensitive to changes than the cost estimates pertaining to the joint biogas plants – the reason being the slightly higher biogas production per tonne of input on farm biogas plants following from the longer retention time at the farm level plants. The difference, however, appear to be insignificant.

C-content of the soil

For the changes in GHG emissions resulting from changes in the C-content of the soil the sensitivity analyses are restricted to the slurry related changes. Hence, the sensitivity analyses are not relevant for the scenarios based on 100 % grass clover. In the analyses the reduction in soil C brought about by biogas treatment of pig slurry is set to 45 kg C per tonne dry matter (DM) in the slurry; in the sensitivity analyses this is changed to 24 (minimum) and 75 (maximum) kg C per tonne DM. For cattle slurry, the reduction applied in the analyses is 33,75 kg C per tonne DM, and in the sensitivity analyses this is varied to 18 and 56,25 kg C per tonne DM.

The effects on the estimated costs of GHG reductions of changing the assumptions regarding changes in soil C following biogas treatment of slurry are shown in Table 19.3. As the results suggest there is no difference in sensitivity across different plant sizes – a logical consequence of the fact that the effect is directly proportional to the amount of input used. Comparing results across input types, it is seen that sensitivity now is inversely proportional to the plant share of input. This follows from the fact that sensitivity only is investigated in relation to changes in soil C related to the slurry part of the input. However, independent of the type of input it appears from the table 19.3 that the results are fairly insensitive to changes in the assumptions regarding changes in soil C. Recent results from the BIOMAN project indicate that anaerobic digestion has a less significant effect on long-term stable soil carbon than anticipated so far (Olesen & Thomsen, unpublished). It is thus likely that the minimum scenario is the most reaslistic. As the effects on GHG costs of changing the assumptions reagarding changes in soil-C are fairly small this will however not significantly change the results of the analyses.

Overall, with reference to table 19.3 it appears that results are significantly less sensitive to changes in the assumptions regarding changes in soil C than they are to changes in the assumptions regarding N_2O and CH_4 emissions. In this connection it is however important to note, that it cannot be dismissed that this is a result of the applied minimum and maximum values, and consequently care should be taken when interpreting the results of the sensitivity analyses. Finally it may be noted that changes in the estimated agricultural GHG emissions have no implications on the financial economic results of the analyses. Hence, adopting GHG reducing practices is not associated with any financial rewards just as changes in agricultural practices causing increases in GHG emissions do not give rise to financial penalties.

Table 19.3 Sensitivity of GHG reduction costs to changes in assumptions regarding agriculturally related GHG emissions (DKK per tonne CO_2 equivalent).

		N_2O		CH_4		Soil C	
Scenarie	Base	min.	max.	min.	max.	min.	max.
1A	745	586	1,020			678	865
1B	721	569	985			658	837
1C	754	599	1,018			690	871
2A	1,390	1,003	2,267	1,311	1,581	1,328	1,491
2B	1,241	896	2,015	1,171	1,410	1,185	1,330
2C	909	657	1,476	853	1,047	868	974
3A	509	416	656			467	585
3B	560	458	721			514	643
3C	525	431	673			482	601
4A	1,743	1,177	3,361	1,609	2,093	1,683	1,838
4B	1,694	1,146	3,247	1,564	2,030	1,635	1,785
4C	1,162	793	2,175	1,068	1,413	1,123	1,223
5A	3,268	1,597	Increased	2,742	5,304		
5B	3,263	1,603	Increased	2,742	5,265		
5C	2,056	1,034	167,043[2]	1,608	3,023		

19.5.2 Sensitivity to a reduction in the demand for transport of biomass

Costs related to the transport of biomass to and from the biogas plants constitute an important component of total costs for all the joint biogas plant scenarios, although the size of transport costs increases with increasing plant share of input due to the fact that it is impossible to drive with return loads when dealing with plant material. It may be argued that the analyses in the present project are based an unrealistically long average distance between the supplying farms and the biogas plants – i.e. 10 km for the 500 tonnes per day plants and 15 km for the 800 tonnes per day plants. The motivation for choosing these distances was that it was important to cover an area sufficiently large to ensure the availability of the required amount of input biomass, and in this connection it was believed that e.g. choosing a distance of 10 km for the 800 tonnes per day plants would not be realistic in many parts of Denmark. Nevertheless, it is considered relevant to investigate the sensitivity of the results to a reduction in the demand for transport of the inputs to biogas production, thereby illustrating the situation that will prevail if the plant can be located in an area where input can be obtained within a more limited area.

The sensitivity analyses are based on investigating the effect of a 50 % reduction in the need for transport of input; the analyses are only conducted for the 800 tonnes per day plants results, and the results are presented in Table 19.4. It may be noted that the reduction in the demand for transport affects results compared to the base case in two ways; it reduces transportation costs and it entails lower GHG emissions. Both effects are accounted for in the presented results. As it is seen in the table reducing the demand for transport of input by 50 % has an effect on results, and although the absolute reduction in GHG reduction costs seems to be increasing with increasing GHG reduction costs, the effect is by no means proportional to GHG reduction costs. Hence, even when reducing the demand for transport by 50 % the

[2] The very high reduction cost is caused by the fact that total GHG reduction becomes very low (13 tonnes).

GHG reduction costs for the scenarios involving plant material continues to be quite high.

Turning to the financial part of the analyses the reduction in the demand for transport of input material will have an impact on the results for the biogas plant which is the actor assumed to be paying for the transport. As seen in Table 19.4. reducing the input related demand for transport by 50 % actually implies that the financial economic result for the biogas plant goes from negative to positive for both scenario 1A and 2A; for scenario 3A the economic surplus becomes significantly greater while for the grass clover scenarios the financial economic result remains significantly negative. Summing up it can therefore be concluded that the degree of sensitivity of the financial results to changes in the input related demand for transport varies across scenarios.

Table 19.4 Sensitivity of GHG reduction costs to a 50 % reduction in the demand for transport of input to biogas production (DKK per tonne CO_2 equivalent).

	Scenario				
	1A	2A	3A	4A	5A
GHG reduction cost (base case)	745	1,39	509	1,74	3,51
GHG reduction costs (50 % reduction in transport demand)	528	1,20	360	1,55	3,17
Reduction in GHG costs	217	181	149	189	337
Financial economic transportation costs (base case)	-3.8	-	-3.8	-	-
Financial result for biogas plant – base case	-	-	0.28	-	-
Financial result for biogas plant (50 % reduction in transport demand)	0.13	1.35	2.18	-	-

In relation to the important role played by transportation costs it may be noted that an alterative to road transport is the construction of a two-way pipeline for transporting both the untreated and the treated slurry. This solution, however, is also quite expensive, and presumably it will only constitute a relevant option in cases involving quite large biogas plants. It should nevertheless be noted that it represents an option which is used in practice, e.g at Mårbjerg Bioenergy (see:
http://www.maabjerg-bioenergy.dk/saadan-virker-det/).

20 Conclusion

The analyses in this report have shown the following:

Biogas production whether based on 100 % pig slurry, 75 % pig slurry and 25 % maize silage, 100 % cow slurry, 50 % cow slurry and 50 % grass clover or 100 % grass clover is found to lead to welfare economic losses. This result is of course highly dependent on the assumptions underlying the analyses in terms of opportunity costs of inputs, transport costs, dry matter content of input and thereby amount of biogas produced and price of natural gas and GHG emissions. Hence, if the assumptions are changed the results will also change. However, it appears that prices, costs and biogas productivity have to change significantly in favour of biogas production to make it welfare economically profitable.

Welfare economic GHG reduction costs per CO_2 equivalent are lowest in scenarios where biogas production is based on 100 % cow slurry. However, these scenarios have the second lowest GHG reduction potential.

CO_2 reduction potential is highest in the scenarios where biogas production is based on 50 % cow slurry and 50 % grass clover, but these scenarios have the second highest welfare economic GHG reduction costs per CO_2 equivalent. Seen from a welfare economic point of view this indicates that the relative desirability of different approaches to biogas production cannot be determined solely with reference to the level of GHG reduction entailed by specific production approaches.

Generally welfare economic GHG reduction costs are lowest for the 100 % slurry scenarios and increase with increased plant share of input. Hence, although the effect of adding plant material is to increase biogas production the value of the increased production is not sufficiently high to compensate for the value of lost plant materials for feed. In this connection it may be noted that the results perhaps would have looked markedly different if a different kind of plant material, e.g. one with zero or at least significantly lower opportunity costs had been used as input. In future analyses it could therefore be interesting to look at plant material that has no real alternative use and/or is grown on areas where no alternative production is displaced.

The analyses are based on quite low slurry dry matter contents. More specifically, the dry matter contents of both pig and cattle slurry are set to reflect the dry matter content experienced in practice rather than the norm based dry matter content. This has important implications in relation to the results of the analyses and if the dry matter contents can be increased, e.g. though changed livestock management practices, it will be possible to attain significantly better both financial and welfare economic results.

The distance between the supplying farms and the biogas plant are assumed to be fairly high in the analyses. Sensitivity analyses regarding the effect of reducing the transport distance reveals that although it reduces costs, the GHG costs remains high particularly for the scenarios involving plant material as input to biogas production.

Investments in biogas production and use of biogas as fuel in power and heat production are heavily subsidized and exempted from environmental taxes. Therefore, increased biogas production implies increased net expenses for the State which entails increased welfare economic tax distortion losses for society.

Whether the analysed biogas scenarios are relevant in relation to Danish CO_2 reduction and renewable energy targets depends on how cost effective the scenarios are compared to other possible CO_2 and renewable energy solutions.

The results of the analysed scenarios relate to specific plant sizes and input combinations. Their welfare economic cost effectiveness with regard to CO_2 reduction can be compared to cost effectiveness of other solutions to fulfil Danish CO_2 and renewable energy targets. It has not been analysed what is the total potential for using the analysed technologies in a Danish context. Answering this question demands further analyses.

In relation to the interpretation of the results it is important to emphasise that the results are inextricably linked to the underlying assumptions. Consequently the results cannot be used as the base for drawing more general level conclusions regarding the welfare economic desirability of biogas production. Seen from a policy point of view, however, the results serve to illustrate the potential inefficiencies introduced by implementing general tax and subsidy structures favouring biogas production. The results of the analyses illustrate how tax exemptions and subsidies contribute to making welfare economically undesirable production approaches financially attractive for private actors. Seen from this perspective, the analysis highlights the importance of targeting policies and designing regulatory instruments in a way that ensures that private actors are provided with incentives to engage in welfare economically desirable biogas production activities and discouraged from engaging in welfare economically undesirable activities.

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Appendix I N$_2$O emissions factors

Fastsættelse af emissionsfaktorer for N$_2$O ved anvendelse af ubehandlet og biogasbehandlet gylle

Af Søren O. Petersen, Inst. for Agroøkologi, AU samt og Mette S. Carter og Per Ambus, Afd. for Biosystemer, DTU-Risø

Bedriftsmodelleringen omfatter forskellige strategier til håndtering af afgrøderester. I nogle scenarier høstes og biogasbehandles kløvergræs, hhv. majsensilage, sammen med gylle, og det afgassede materiale benyttes efterfølgende som gødning til afgrøder i sædskiftet. Der opereres med både sandede (JB1-3, 0-10 % ler) og mere lerholdige jorde (JB5-6, 10-15 % ler). Dette notat foreslår et grundlag for fastsættelse af emissionsfaktorer for ubehandlet og biogasbehandlet gylle og for biogasbehandlede afgrødematerialer. Der findes ikke forsøgsresultater, som dækker hele det sæt af scenarier, der skal regnes på. Derfor er emissionsfaktorerne baseret på en kombination af måledata og mere kvalitativ viden fra litteraturen, bl.a. vedrørende effekt af biogasbehandling på emissionen af lattergas (N_2O).

Lattergas kan dannes af nitrificerende og denitrificerende bakterier. Gylle indeholder NH_4^+-N, som vil stimulere nitrifikationen, og nedbrydeligt organisk materiale, som kan stimulere denitrificerende bakterier. For begge processer gælder det, at iltfattige forhold vil stimulere dannelsen af N_2O.

Konceptuel beskrivelse af gylleudbringning

Gylle udbragt på ubevokset jord og fodergræs skal efter gældende regler nedfældes, medmindre den behandles med forsuring (BEK nr. 114 af 11/02/2011). I vintersæd kan gyllen udbringes med slæbeslanger, hvilket kan føre til højere ammoniaktab og dermed reducere potentialet for N_2O emission. Dette notat forholder sig dog kun til risikoen for N_2O emission fra indarbejdet gylle.

Sommer et al. (2004) præsenterede et værktøj til estimering af N_2O-emission fra udbragt gylle. En simpel model beskriver fordelingen af gyllens væskefraktion, og C og N opløst heri, som funktion af tørstofsammensætning og jordens vandpotentiale på udbringningstidspunktet. Principielt forudsiger modellen, at jo mere (organisk) tørstof gyllen indeholder, desto mere vil den binde væsken i et volumen, hvor iltforbrug og potentiale for N_2O-dannelse er relativt stort. Omvendt vil et lavt tørstofindhold fremme infiltrationen og mindske risikoen for N_2O-dannelse.

Model-værktøjet forudsiger, at biogasbehandling af gylle fører til mindre N_2O-emission. Biogasbehandling fjerner tørstof og reducerer viskositeten, så alt andet lige vil det sikre en bedre fordeling af gyllens C og N i jorden end det er tilfældet for ubehandlet gylle. For jorde med god beluftning, typiske sandede jorde, er en reduktion af N_2O-emissionen fra gylle sandsynlig; en dansk undersøgelse (Petersen, 1999) og flere udenlandske undersøgelser, mest i laboratorieskala, har understøttet modellens forudsigelser vedr. effekt af biogasbehandling. For mere lerholdige jorde har man derimod ikke fundet en sådan effekt, og i nogle tilfælde endda tegn på det modsatte (Clemens et al., 2006; Pattey et al., 2007; Chantigny et al., 2010). Det gjaldt også et dansk markforsøg ved Forskningscenter Bygholm (JB5-6) (Thomsen et al., 2010). Årsagen kan være, at en dårligere beluftning forskyder denitrifikationen i retning af frit kvælstof sammenlignet med en mere sandet jord (Thomsen et al., 2010). Den samme effekt kan et højt vandindhold have.

Den foreliggende model er ikke gældende for jorde med et begrænset luftskifte, dvs. med højt lerindhold og/eller høj jordfugtighed. Det forudsættes med andre ord, at jorden er veldrænet på udbringningstidspunktet.

Tilsætning af afgrøderester under udrådningen

Biogasbehandling af gylle sker typisk med tilsætning af organisk affald, evt. plantemateriale, fordi letnedbrydeligt organisk stof fremmer gasproduktion og dermed rentabilitet. Plantemateriale som fx majsensilage kan også udrådnes alene. I en kontinuert proces med daglig udskiftning af 5-10 % af reaktorvolumenet vil der altid være en andel af frisk materiale, som passerer hurtigt igennem reaktoren. Afhængigt af lagringstid og –betingelser kan det påvirke C- og N-omsætningen i jorden. En tysk undersøgelse (potteforsøg) med tilførsel af biogasbehandlet majsensilage (uden gylle) til en sandet jord (12 % ler, 29 % silt, 59 % sand;Senbayram et al., 2009) resulterede i N_2O-emissioner på 2,56 % fra materialet mod 0,65 % fra handelsgødning.

Et afsluttet dansk projekt, Bioconcens, fandt at N_2O-emissionen igennem 2 måneder efter udbringning af ubehandlet kvæggylle, eller udbringning af afgasset kvæggylle tilsat afgasset majsensilage (Carter et al., in press) eller afgasset kløvergræs på sandblandet lerjord (JB4), var på samme niveau. Resultater fra laboratorieforsøg i Bioconcens- og Bioman-projekterne peger i samme retning, nemlig at biogasbehandling af kvæggylle alene mindsker risikoen for N_2O-emission, mens tilsætning af planterester under udrådningen har tendens til at ophæve denne effekt.

Emissionsniveau, danske jordtyper

Der er gennemført en årstidsundersøgelse af N_2O-emissioner på Foulum (JB4) og Flakkebjerg (JB6), som kan siges at repræsentere hhv. JB1-3 og JB5-6. Her blev målt årlige emissionsfaktorer for ubehandlet svinegylle ved tildeling til vinterhvede i forskellige sædskifter, se tabellen herunder (Chirinda et al., 2010). Emissionerne i højre kolonne angiver N_2O-tabet som procent af N i gødningen, gennemsnitsværdierne var 0.71 % for Flakkebjerg og 0.64 % for Foulum. Disse værdier ligger på et lavere niveau end den 1 %, som IPCC anbefaler som default-værdi (IPCC, 2006), formentlig et udtryk for at vore jordtyper er relativt lette. Målinger igennem 2 mdr. efter gylleudbringning i et dansk projekt, Bioconcens, peger derimod på emissionsfaktorer på 1-3 % for ubehandlet kvæggylle (Carter et al., in press). Med udbringning i maj kan der muligvis være en temperatureffekt sammenlignet med gylletildeling midt i april – modelværktøjet forholder sig ikke til en temperatureffekt.

Annual cumulative N_2O flux, winter wheat grain yields, and emission factors by yield and by N applied in four cropping systems located at Flakkebjerg (FL) and Foulum (FO).

Site/system	Cumulative N_2O emission[a] ($mg\,N\,m^{-2}$)	Grain yield ($kg DM\,m^{-2}$)	Emissions per yield ($mg\,N_2O\text{-}N\,kg^{-1}\,DM$)	Emissions per N applied[b] ($kg\,N_2O\text{-}N\,100\,kg^{-1}\,N$)
FL/C4 – CC	137^{a}	0.76^{a}	184^{a}	0.81^{a}
FL/O4 – CC	71^{a}	0.28^{b}	274^{a}	0.70^{a}
FL/O4 + CC	54^{a}	0.38^{b}	133^{a}	0.53^{a}
FL/O2 + CC	80^{a}	0.39^{c}	205^{a}	0.80^{a}
FO/C4 – CC	92^{a}	0.95^{a}	96^{a}	0.56^{a}
FO/O4 – CC	68^{a}	0.50^{b}	134^{a}	0.63^{b}
FO/O4 + CC	81^{a}	0.63^{c}	130^{a}	0.75^{b}
FO/O2 + CC	63^{a}	0.58^{bc}	108^{a}	0.62^{b}

At each site values with the same letter within a column are not significantly different ($P < 0.05$).

[a] Cumulative flux for 313 and 365 days at FL and FO, respectively.

[b] See Table 2 for the amount of N applied in the different treatments plots in 2008.

Emissionsfaktorer i modelleringen

Der er ikke med de kendte danske undersøgelser grundlag for at konkludere, at N_2O-emissionen fra gylle afgasset sammen med planterester er mindre end fra ubehandlet gylle. Derfor benyttes samme emissionsfaktorer for ubehandlet gylle som for de materialer, der anvendes i scenarie 2, hhv. 4 for ubehandlet svine- og kvæggylle.

De fleste emissionsfaktorer er højere end IPCC's standard-emissionsfaktor for N_2O fra gødning, som er 1 % af total N uanset gødningens sammensætning. Dog forudsættes det, at N_2O-emissionerne i tabellen herunder dækker både den direkte emission og den indirekte emission, som senere vil komme fra fordampet ammoniak. Dermed bliver emissionsfaktorerne også mere uafhængige af udbringningsmetode.

I de beregninger, som er gennemført, forudsættes dermed følgende:

Det forudsættes, at gylletildeling stimulerer N_2O-emission, dvs. at der ikke er situationer med så dårligt luftskifte, at tilførsel af organisk gødning reducer N_2O-emissionen.

Det forudsættes, at gylleudbringningsmetoden, og dermed fordelingen i jorden, er den samme i alle scenarier

Lattergasemissionen fra udrådnet gylle sættes til 1 % ved udbringning i april og til 2 % ved udbringning i maj.

Samudrådning af gylle med letnedbrydelige afgrøderester giver ikke nogen reduktion i potentialet for N_2O-emission.

Anvendelse af udrådnet afgrødemateriale alene har et forhøjet potentiale for N_2O-emisison, som sættes til 3 % uanset udbringningstidspunkt.

Det forudsættes på grundlag af ovenstående overvejelser, at den årlige N_2O-emission for ubehandlet kvæg- og svinegylle er 1.4-2 % i april og lidt højere i maj, jfr. tabellen.

Det forudsættes, at gylle gives til majs i maj, og til alle øvrige afgrøder i april.

Det forudsættes, at emissionsfaktorerne herunder omfatter både den direkte N_2O-emission og den indirekte N_2O-emission fra ammoniakfordampning.

De forskellige scenarier, som modelleres, er vist herunder sammen med de valgte emissionsfaktorer:

	JB1-3		JB5-6	
	Apr	Maj	Apr	Maj
1 100 % svinegylle – afgasset	1	2	1	2
2 75 % svinegylle, 25% majsensilage - afgasset	1,4	2,25	1,4	2,25
3 100 % kvæggylle (økologisk) - afgasset	1	2	1	2
4 50 % kvæggylle (økol.), 50% kløvergræs (økol.) - afgasset	2	2,5	2	2,5
5 100 % kløvergræs (økologisk) - afgasset	3	3	3	3
6 Referencescenarier m. svinegylle - ubehandlet	1,4	2,25	1,4	2,25
7 Referencescenarier m. kvæggylle – ubehandlet	2	2,5	2	2,5

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SOCIO-ECONOMIC EVALUATION OF SELECTED BIOGAS TECHNOLOGIES

Financial and welfare economic analyses are condcted of 15 different biogas production scenarios that vary in terms of plant size and type of input. All considered scenarios lead to welfare economic losses. Overall welfare economic GHG reduction costs seem to increase with increasing crop/crop material share of input, and although the costs vary significantly across scenarios they are quite high for all scenarios. The financial analyses suggest that biogas production generally will be financially profitable for the agricultural sector and local CHP facilities but unprofitable for the biogas plants and the State. Seen from a policy perspective the results highlights the importance of designing regulatory instruments in a way that create incentives for private actors to engage in welfare economically desirable biogas production activities while discouraging the expansion of welfare economically undesirable activities.

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