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European Biogas Workshop

The Future of Biogas in Europe - III

14 - 16 June 2007
University of Southern Denmark
Esbjerg, Denmark

Intelligent Energy Europe

European Biogas workshop and study tour

The Future of Biogas in Europe III

14th -16th of June 2007

University of Southern Denmark, Niels Bohrs Vej 9, 6700 Esbjerg

Esbjerg - Denmark

PROCEEDINGS

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Project co-ordinator:
University of Southern Denmark
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Colophon

European Biogas Workshop – The Future of Biogas in Europe III

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Thank you all for a great team work.

Teodorita Al Seadi, Editor and Coordinator of the PROBIOGAS project.

WORKSHOP PROGRAMME

Thursday, 14 June 2007:

12:00-13:00	Registration and quick lunch

Biogas from anaerobic digestion in a European perspective

13:00-13:10	Welcome and opening address By Teodorita Al Seadi - PROBIOGAS coordinator University of Southern Denmark, Esbjerg, Denmark
13:10-13:30	Biogas, an important player within the European renewable energy strategy Outlook for European and Danish policy framework for biogas and bioenergy By Kim Mortensen, member of the Danish Parliament

Implementing biogas from centralised co-digestion in Europe: Assessment results from the PROBIOGAS project

13:30-13:50	"If you can't find a way, make a way"- The concept and objectives of PROBIOGAS By Teodorita Al Seadi, University of Southern Denmark, Bioenergy Department, Esbjerg, Denmark
13:50-14:20	Economic effects, barriers, and incentives of biogas from centralised co-digestion By Kurt Hjort-Gregersen, University of Copenhagen, Institute of Food and Resource Economics, Copenhagen, Denmark
14:20-14:50	Environmental externalities of centralised co-digestion By Sven G. Sommer, Danish Institute of Agricultural Sciences, Horsens, Denmark
14:50-15:20	Socio-economic aspects of centralised co-digestion By Lars Henrik Nielsen, Risoe National Laboratory, Roskilde, Denmark
15:20-15:50	*Coffee break*

Biogas in Europe: Best-practice examples of non-technical barriers break down

15:50 -16:20	The impact of national policies and economic frames for the development of biogas in Germany By Gepa Porsche and Claudius da Costa Gomes, German Biogas Association, Freising, Germany
16:20 -16:50	Efficiency of energy crop digestion - evaluation of 41 full scale plants in Austria By Rudolf Braun, Institut für Umweltbiotechnologie, Interuniversitäres Department für Agrarbiotechnologie - IFA Tulln Universtät für Bodenkultur Tulln, Austria
16:50 -17:20	Biogas upgrading and utilisation as vehicle fuel By Margareta Persson, Swedish Gas Center, Malmö, Sweden
17:20-17:50	AD on the move – United Kingdom 2007 By Clare Lukehurst, United Kingdom
17:50-18:15	A farmers' experience as a member of a centralized co-digestion plant By Henrik Høeg, Danish Biogas Association
18:15-18:45	Panel discussions
19:15 -	*Workshop Dinner*

Friday, 15 June 2007:

Biogas in Europe: Technologies, trends, visions

09:00- 09:30	Innovative AD technologies for solving the farmer's problem of excess manure. Example and results from the Pig-man project in Denmark By Rena Angelidaki, Technical University of Denmark, Inst. of Environment and Resources, Lyngby, Denmark
09:30 -10:00	Current state and new biogas initiatives in Bulgaria By Ivan Simeonov, Institute of Microbiology-Bulgarian Academy of Sciences, Sofia, Bulgaria
10:00 - 10:30	Veterinary safety in relation to handling of manure and animal by products and the use of biogas technologies By Dorthe L. Baggesen, Technical University of Denmark, National Food Institute, Copenhagen, Denmark
10:30-11:00	*Coffee break*
11:00- 11:30	Digested manure is a valuable fertiliser By Torkild Birkmose, Danish Agricultural Advisory Service, Skejby / Aarhus N, Denmark
11:30-12:00	Further technical development and economic sustainability of co-digestion By Johannes Christensen, University of Copenhagen, Institute of Food and Resource Economics, Copenhagen, Denmark
12:00 -12:30	The future of biogas in Europe: Visions and targets until 2020 By Jens Bo Holm-Nielsen – Centre of Ind. Biotechnology and Bioenergy Aalborg University & University of Southern Denmark, Esbjerg, Denmark
12:30-14:00	Lunch

Incentives vs. barriers and how to move further: Outcomes of the PROBIOGAS case study assessments

14:00-14:30	Future for large scale digestion in the Netherlands? By Bert Van Asselt, SenterNovem, Utrecht, the Netherlands
14:30-15:00	Analysis of the needs and opportunities for the setting up of a centralised co-digestion plant in the grazing area of the Province of Liège By Fabienne Rabier & Gaëlle Warnant, Agric. Research Centre, Agric. Eng. Dep. & ValBiom asbl, Chaussée de Namur, Belgium
15:00-15:30	Overview of centralised biogas plants projects in France. Will the new economic incentives By Christian Couturier, Association SOLAGRO, Toulouse, France
15:30-16:00	*Coffee break*
16:00-16:30	Achieving environmental and agricultural benefits from centralised co-digestion in Ireland By Vicky Heslop, Methanogen Ltd., Tooracuragh, Ireland
16:30-17:00	Barriers and incentives of centralised co-digestion in Spain. Case study of Pla d'Urgell, Catalonia By Joan Mata-Álvarez, University of Barcelone, Dept. of Chemical Engineering, Barcelona, Spain

17:00-17:30	Biogas in Greece: Current situation and perspectives By Christos Zafiris, Center for Renewable Energy Sources, Pikermi, Greece
17:30 – 18:00	Panel discussions
18:00 -18:15	Closing address Teodorita Al Seadi, SDU-Denmark
18:15	End of the workshop and the afternoon at your disposition

Saturday, 16 June 2007:

Guided study tour to biogas sites in Jutland, Denmark

8:30	Departure by bus from SDU, Esbjerg
8:30-10:30	Bus travel and guided tour to Blaabjerg centralised co-digestion plant, in the south-western part of Jutland
10:30-11:45	Bus travel and guided tour to Hegndal farm scale biogas plant and post-separation facilities, in the south-western part of Jutland
11:45-13:30	Bus travel and lunch in Filskov town, situated in the central part of Jutland
13:30-14:30	Guided tour to Filskov Energy Company
14: 30- 16:00	Bus travel to Esbjerg

NB: Driving back to Esbjerg we will stop at Billund Airport, around 14: 45 and at Esbjerg Airport, around 15:45

16:00	Back to SDU, Esbjerg

Contents

Opening address

By Teodorita Al Seadi- PROBIOGAS coordinator
University of Southern Denmark, Esbjerg, Denmark

Ladies and gentlemen, dear colleagues and friends, on behalf of the organisers of the European Biogas Workshop"The Future of Biogas in Europe III", I wish you all a warm welcome.

As the title reveals, this is the third in a series of European workshops organised by the University of Southern Denmark, in collaboration with partners from all over Europe. The workshop is co-financed by the European Commission, the Intelligent Energy Europe Agency through the PROBIOGAS project. For this reason a part of the workshop sessions is dedicated to communicating the results of this project.

Large scale development of sustainable systems for production of renewable energy, to replace the fossil fuels, is one of the greatest challenges of our time, in the battle of preventing further environmental deterioration and climate change, which we have no other choice but to win. Renewable energy can be produced from a variety of renewable sources and by a multitude of concepts and technologies. It is up to us today to integrate, further optimise and adapt them to local conditions, resources and necessities.

The summit of the G8 countries, recently taking place in Germany, ended with the conclusion that the CO_2 emissions must be reduced by 50% by year 2050, but no mandatory agreements were made in this direction. The new chance for it will occur in 2009, when the climate summit in Copenhagen hopefully will bring along the long expected agreements. The more aware the large public becomes, the higher their expectations are for the politicians to take proper action. It is therefore important that scientists make their knowledge public and accessible to the large public.

There is no doubt that biomass, in its many forms, is one of the most important renewable resources of our planet. A resource that contains clean solar energy, captured throughout the ingenious process of photosynthesis. The accomplishment of the goals of the Kyoto protocol and the EU strategy for increasing the share of renewable energy in the total energy consumption, give biogas from co-digestion of animal manure and digestible bio-wastes an important role, as one of the key technologies within the large family of biomass based energy. Biogas is a source of renewable energy and vehicle fuel, providing benefits for the environment, the farmers and the society as a whole. It improves nutrient management and veterinary safety and it is a cheap tool in controlling greenhouse gas emissions.

The aim of the workshop is to provide an up-date of the existing knowledge, know how and expertise in the area of biogas from anaerobic digestion, to show successful examples of barriers breakdown and to look upon further strategies for the development of biogas technologies in Europe.

I wish you all an inspiring and fruitful workshop and an enjoyable stay in Esbjerg.

“If you can’t find a way, make a way”- The concept and objectives of PROBIOGAS

By 1) T. Al Seadi, 2) K. Hjort-Gregersen, J. Christensen, H.B. Moller , S.G. Sommer 3), T. S. Birkmose 4), L.H. Nielsen 5), B. v Asselt 6), F. Rabier, G. Warnant 7), C. Couturier 8), J.M. Alvarez 9), C. Zafiris 10), V. Heslop 11)

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Introduction

Anaerobic digestion of animal manure is a multifunctional concept, providing quantifiable environmental and economic benefits for agriculture, food industries, energy sector and the overall society and an effective tool in reducing green house gas emissions. The main objective of PROBIOGAS is to assess and quantify the environmental effects and the economic and socio-economic potential of biogas from centralised co-digestion by applying an assessment method and the knowledge gathered throughout two decades of research in Denmark. This is done in selected case study regions of six European countries, where biogas technologies are not developed. The project is co-financed by EC throughout the IEEA, the ALTENER Programme.

Over the last 30 years considerable progress was made in Denmark in developing cost efficient biogas production systems. The process was initiated by the oil crises in the early 1970s, when a number of small-scale pilot plants were built, processing animal manure and other suitable biomass from a single farm. But it soon became clear that a larger plant, collecting and processing manure from several farms, had a significantly improved performance and a range of advantages of scale. This way the centralised co-digestion concept was born and its development continued throughout the coming decades, with the support of governmental RD&D programmes.

In the beginning, the predominant interest in biogas from anaerobic digestion was driven by the production of renewable energy. Later on, as awareness about the environmental impacts of livestock production and manure handling increased and national regulations in this field became significantly restrictive, animal farmers faced mandatory requirements of storage capacity for their manure, restrictions concerning the amounts, and the seasons for manure application as fertiliser. They could get important economic support from the government, to help them comply with the new regulations, but the support was conditioned of supplying the manure to a co-digestion biogas plant. This way, the Danish government created a favourable framework, where the farmers became the driving force for the development of biogas from centralised co-digestion, in the decade 1985-95.

Experience showed that centralised co-digestion could provide a wide range of economic and environmental benefits, not only by production of renewable electricity and heat, but also by improved manure management, reduced nutrient losses and emissions of methane and nitrous oxide from storage and land application, reduced odours and increased veterinary safety from animal manure application. At the same time, it offers a safe recycling of suitable organic by-products from agriculture and food industry.

Centralised co-digestion of animal manure in Denmark is today a mature technology, economically sustainable and a cost efficient tool for reducing the emissions of green house gases (GHG) and environmental improvement. This was documented by the Report no. 136 *Socio-economic analysis of centralised biogas plant*s, published by Danish Research Institute of Food Economics in 2002. For the first time, a range of externalities from biogas from anaerobic co-digestion were quantified and monetised, revealing the environmental, economic and socio-economic benefits for the society. This kind of documentation is needed in many other EU countries, where the biogas technologies are not developed and it is essentially the background for the PROBIOGAS project work.

Why PROBIOGAS?

Many biogas projects are abandoned at an early stage as the potential investors and promoters are often unaware of the business opportunities and the economic and environmental benefits associated with biogas systems. The lack of awareness would not allow them to undertake the assessments required, to negotiate appropriate agreements and to obtain the necessary financing.

The experience from Denmark proves that biogas from centralised co-digestion is a multifunctional concept, providing quantifiable environmental and economic benefits for agriculture, industry, energy and the overall society, and could be an important tool in controlling GHG emissions from agriculture and the waste management. Quantification of the potential environmental and socio-economic effects of centralised co-digestion in regions with environmental problems caused by intensive agriculture and no incentives for biogas production reveals the benefits that could be achieved by implementing this technology and highlights some important non-technical barriers, which must be removed in order to make biogas from co-digestion a lucrative activity.

The work of the project is based on the results of the research carried out in 2002 by a team of Danish researchers, where environmental and economic costs and benefits of the centralised biogas technology, derived advantages and drawbacks are quantified and monetised using a welfare-economic methodology. The main objective of the project is to assess these aspects for selected case study regions in six European countries, where biogas technologies are not developed, and to disseminate the obtained results to the target groups and to the overall European level.

The project activities and results are aimed to raise awareness about biogas technologies, as a socio-economic and environmental beneficial activity that can contribute to achieving national environmental targets.

Promoters and target groups

The promoters of the project are:
University of Southern Denmark- Bioenergy Department, Denmark; Danish Research Institute of Food Economics, Denmark; Risoe National Laboratory, Denmark; Danish Institute of Agricultural Sciences, Denmark; Danish Agricultural Advisory Centre, Association Solagro, France; University of Barcelona, Spain; Centre for Renewable Energy Sources, Greece; Methanogen ltd, Ireland; SenterNovem, the Netherlands and Agricultural Research Centre of Wallonia, Belgium.

The accomplishment of a biogas project is very complicated and involves a range of actors; physical persons, organisations, and authorities. It is important that all the involved parts in a biogas project realise the potential for their specific interests and interact with a variety of members of the target group: policy makers, local authorities and municipalities, farmers and farmers' associations, biogas specialists, energy and energy trade companies, energy and environmental agencies, food processing industries etc.

For the reasons mentioned before, a target group network was formed for each case study region, at the beginning of the project. The project team interacted with the specific target groups from the early stage of the project and introductory workshops were organised in each participant country. It was intended that the target group networks should form the organisational structure, necessary for project generation in the respective regions.

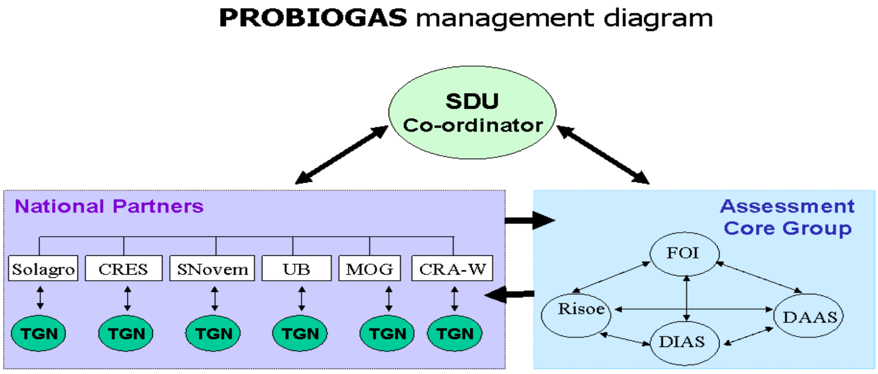

Figure 1. Management diagram of PROBIOGAS

The role and the interests of the members of the target groups are different from case to case. In countries where removal of non-technical barriers and legal changes are crucial for the development of biogas, policy makers are an important target group. Local and regional authorities will be involved in the approval process while energy trade companies will be interested in the new market opportunities of the renewable electricity and heat. The energy agencies are those formulating the national energy strategies, so it is important that they understand the multifunctional nature of co-digestion and that it is a competitive tool in GHG reduction and environmental improvement, while for food processing industries co-digestion is an environmental and economical favourable way of recycling of organic waste. Last but not least, the farmers, suppliers of manure and receivers of digested biomass, should be aware of the costs and the benefits of the technology, for both their economy and the environment.

The case studies

The selected case studies are represented by regions with intensive livestock production, with a certain potential for biogas production and with no or very little developed biogas technologies.

Some of the main criteria for selection of a region as a case study were:

- Intensive animal breeding activity/ production of large amounts of animal manure and slurries
- Environmental problems related to manure handling and application (odours, flies, eutrofication of rivers and of other water environments, uncontrolled emissions, nutrients in the ground water etc.
- Availability and accessibility of other types of digestible biomass (by-products from food industries, farming, fishing etc.
- Possibilities of CHP generation and of sealing the produced energy (electricity and heat)
- Possibilities of using digested biomass as bio-fertiliser
- Reasonable average transportation distance for manure and slurry
- Good road systems
- Interested farmers

It was almost impossible to find areas that could fulfil all the above, criteria. The most important of them all was the existence and availability of the biomass substrate (animal manure, organic by-products of various origins) and the need to find better ways for their management and recycling

Based on the above criteria, following regions were selected as case studies for the PROBIOGAS project:

- **Ireland:** North Kilkenny County
- **The Netherlands:** Bladel, region De Kempen, North Brabant
- **Belgium:** Province of Liege, Wallonia
- **France:** West Aveyron, Midi-Pyrénées
- **Spain:** Pla d’Urgell, Catalonia
- **Greece:** Sparta, Tsikakis-Yiannopoulos pig farm

Ireland: North Kilkenny County

The region chosen for the Irish case study is situated around Ballyragget, in North Kilkenny. This location is centrally situated within the whole of Southern Ireland, in a sparsely populated area, crossed by two significant waterways, Nore and Barrow. Most surface water has high, and some parts extremely high, nitrogen levels. There are now some signs of increasing nitrogen levels in ground water as well, originating from rural communities sewage, much of which untreated, and from agricultural runoff. Eutrophication caused by phosphate is also present in local areas.

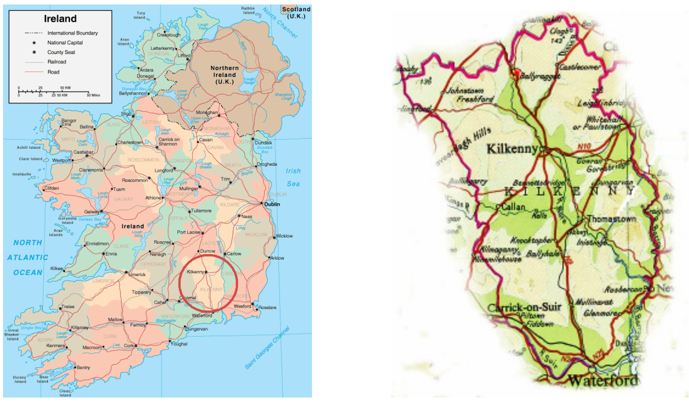

Figure 2. Map of Ireland. Kilkenny County is marked by the red circle

The site is situated adjacent to a very large milk processing plant (processing approx. 50% of Ireland's milk production). The co-digestion plant could process all the sludge and fatty waste produced by the factory. About 40 dairy and cattle farms in the area could supply slurry, farmyard manure, silage effluent, and other organic material. The size of these farms varies from about 30 to 350 livestock units. All are situated within 8 km of the proposed site.

The plant could process several types of non-farm substrates from the surrounding area. However, due to current national rules concerning animal by-products, which prohibit the use of fertilisers containing meat products to be used on grassland, it was decided to assume that the plant will only process materials that can be used on grassland.

60-70 farms could be involved with the co-digestion plant, some of the crop farms utilising the digested biomass as bio-fertiliser. The manure required will be supplied by about 5,700 LU of cattle. The time that these cattle are housed varies from farm to farm, age and type of stock, year and weather conditions. Some animals may only be housed for about 50 days, others 160 days. The systems currently used to manage and store the slurry will mean that manure can be supplied to the plant all year round.

It is expected that about 1.1 mill. m^3 of methane (1.7 million m^3 of biogas with 60% methane content) will be produced each year. About 10% of the biogas produced could be utilised in a CHP-unit on site, to supply process energy and the excess of electricity will be sold to the national grid. Some of the biogas produced will be used to replace natural gas in the steam boilers of the factory.

The digested material will be used on both grassland and arable land as a fertiliser (about 80% as separated liquor and 20% as separated fibre). Some of the fibre fraction will be sold as a base for horticultural compost.

Spain, region of Pla d'Urgell, province of Lleida

The case study is concentrated on a farm located in Vilasana, which is a municipality of Vilaplana, in the region of Pla d'Urgell, within the province of Lleida (see Figure 1). This is a rather dry region with a low density of inhabitants dedicated to agriculture and farming.

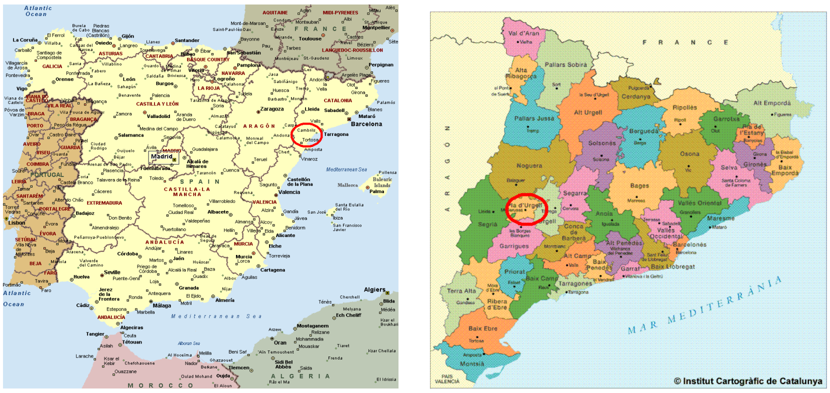

Figure 4. Map of Spain. The case story region is marked by the red circle

This region, Pla d'Urgell, has around 320,000 pigs concentrated in 250 of farms, which represent around 4% of the total livestock units in Catalonia. Vilasana, one of the municipalities, with an area of 19,3 km^2 and 540 inhabitants, has 15 farms and 26,000 pig livestock units. All the pig farms in the area produce a total of 129,500 tonnes of slurry per year, the cattle farms 30,000 tonnes per year. Together with poultry manure and the residues from food industry, the amount of digestible biomass is 170,000 tonnes per year.

It seems that a centralised co-digestion plant could help in reducing the cost treatment for industrial wastes, potentially increase the fertiliser value of manures and decrease the GHG emissions due to manure storage. In addition biogas would be produced which could be transformed into electricity and heat. Unfortunately, heat could not be used for district or industrial heating, because of the distances and the climate conditions. Another added benefit of centralised co-digestion would be the reduction of odours.

Belgium, Sprimont, Province de Liege, NE of Wallonia

The chosen area in the Belgian case is located in the Province de Liège, one of the 5 provinces of the Walloon part of Belgium (Northeast of Wallonia)

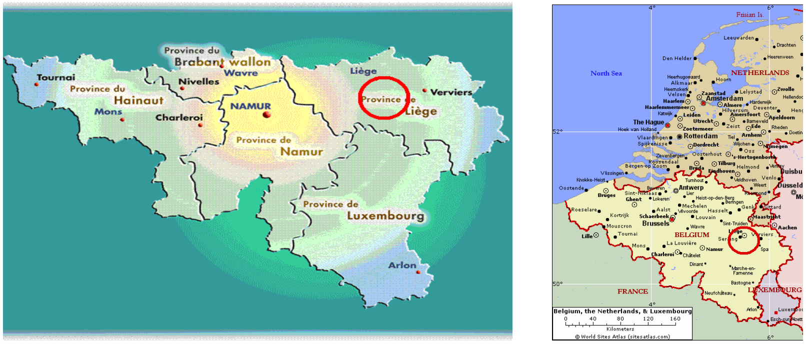

Figure 5. Walloon part of Belgium and its provinces. The case study is marked by the red circle

The chosen area is specialised in milk production with more than 35,000 cows. Additionally, some large pigs and poultry farms are also located in this area. 40 farms are included in the case study: 20 in the Commune of Sprimont and 20 in the commune of Limbourg. The total agricultural area, where the manure is spread, is about 2,200 ha. The main crops in this area are fodder crops such as maise and grass. The following tables summarised the quantity of agricultural manure, which can be collected among the 40 farms. The manure will not require processing before digestion.
There are several potential users of the heat. Other financial gains could be obtained by the Green Certificates that the biogas unit could get. The calculation of the number of the Green Certificates is made by the Walloon Commission for Energy.

Very few food processing industries are interested in a biogas project, as cost for present waste treatment is not very high. A big part of their by-products are bought by the farmers and used as animal feeds.

Greece, Laconia, Peloponnesus region

The chosen region for the Greek case study is situated around Sparta, the capital city of the prefecture of Laconia, in Peloponnesus region. It is situated in the north west of the prefecture, to the east of the mountain Taigetos at an altitude of 210 m. The climate is Mediterranean and the average yearly temperature 17.4°C while average yearly rainfall, even present during summertime, is 817 mm. Because of the particularity of the climate and the fertile territory, the economy is mostly self-supported. The region's farming and cattle rearing products are gathered and processed in the city's own industrial units.

Figure 6. Map of Greece and of province of Peloponnese /Sparta. The case study area is marked by the red circle

The risk of water pollution of both ground and surface waters is quite high in the area, because there are lots of agricultural activities and relatives industries. The Prefecture of Laconia has edited a document entitled “The water use for irrigation in Evrotas river”, which defines the disposal limits of the treated waste water in the river of Evrotas that surrounds the city of Sparta.

The digestible biomass in the region originates from the agricultural sector as well as from agro–food industries. The main categories are:

- Animal slurries and stomach contents
- Animal fat and bones
- Liquid wastes from dairy industry
- Residues from citrus fruit processing
- Residues from oil mills (primary and secondary processing)

The possible site for the establishment of a co-digestion plant is the "Tsikakis – Giannopoulos" enterprise, situated some 10 km from the city of Sparta and consisting of a pig farm, a slaughterhouse and a meat factory. The pig production of the farm is about 14,200 fattening pigs per year. The produced pig slurry (about 100 m^3 per day) is treated in an aerobic treatment plant next to the pig farm. The slurry is collected in a tank followed by mechanical screening for solids separation. The wastewaters from the slaughterhouse and the meat factory are also treated by the same plant through a Dissolved Air Floatation system (DAF). The sludge volume collected by the DAF system is about 1.5 m^3 per day.

Furthermore, the integrated farm structure with pig production and slaughterhouse is ideal for setting up biogas plants, because of large amounts of on-site available biomass and high energy consumption in the particular plants.

The biogas plant could supply 100% of the electricity and heat demand to the farm/slaughter-house and export approx. 1,5 GWh electricity/year to the grid. Additionally, there are huge surpluses of heat that can be transformed to heating and cooling for in-house use.

France: Midi Pyrenees, West Aveyron area

The French case study is located in the "Pays du Rouergue Occidental", the west part of the department of Aveyron, in région Midi-Pyrénées (South-West of France).

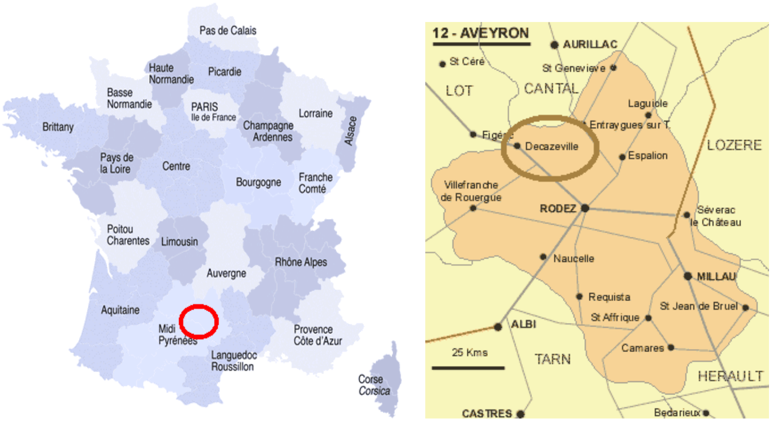

Figure 7. Map of France and of Aveyron region. The case study area is marked by the red circle.

The manure production in West Aveyron is estimated at 1 mill. tonnes (160,000 tonnes of dry solids), of which 2/3 arise from cow breeding and 1/3 from swine.

Many food industries are established near the main cities in a 20-30 km radius area. Most of them are meat industries. The biogas project could be a solution for 6,000 to 9,000 tonnes of wastes and by-products.

The centralised anaerobic co-digestion plant could be built in the neighbourhood of Montbazens and will process mainly swine and cattle liquid manure, some quantities of solid cattle manure and several types of non-farm wastes from the surrounding area. The plant will be supplied by 20-30 farmers, within a radius of about 10 km on the Montbazens plateau. The area is delimited by River Lot and River Aveyron valleys, and the hillsides are a difficulty for the transportation of the manure out of the area.

The heat produced by the Combined Heat and Power (CHP) plant could be used by a food-industry. The raw biogas will be carried by a biogas pipeline of about 13 km from the plant to the food industry plant. The CHP will deliver electricity to the grid, and will generate steam for the industry process. District heating for 5,000 households in the city of Capdenac Gare or Decazeville city are also considered, although the gas transmission pipeline should be of 15 km.

In France, electricity from renewable sources is bought by the distribution companies, such as EDF, at a tariff established by the government and for the West Aveyron is of 130-135 EUR/MWh.

The digested material will be used on both grassland and arable land as a fertiliser. Today, farmers use mineral nitrogen in addition to raw manure. Anaerobic digestion will bring a positive nitrogen balance, so farmers could save on purchasing mineral nitrogen and export the excess to arable crops. One key-point is the acceptance of waste spreading on farmlands. Farmers are very sensitive to the quality of digestate: control of incoming wastes, analysis of digestate, fertilising value etc.

The Netherlands, Noord Brabant, region De Kempen, community of Bladel

As Dutch case for the European PROBIOGAS project, SenterNovem chose an initiative in the southern part of the Netherlands, region De Kempen, in the community of Bladel (South-West of Eindhoven). This region is characterised as an intensive agricultural area. The animal slurry production is of 2,6 mill. tonnes per year, originating from pig, cattle and from poultry farms.

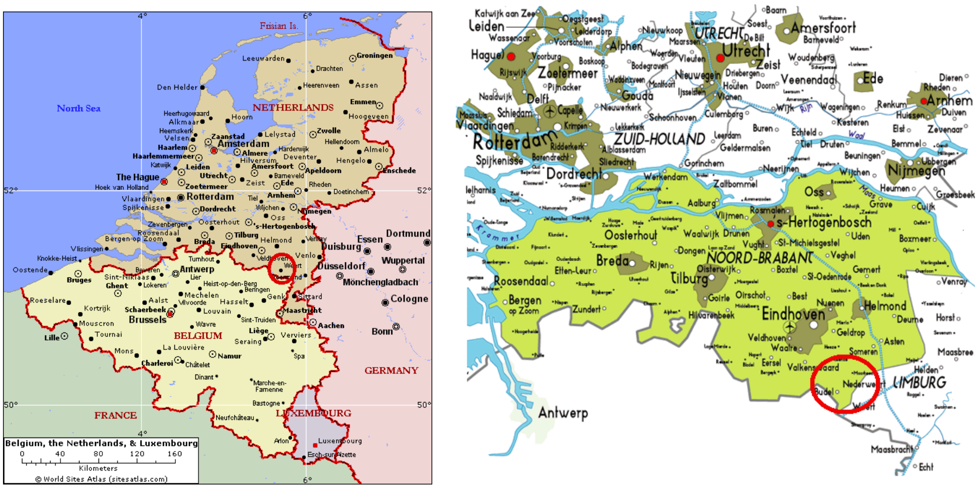

Figure 8. Map of the Netherlands and Noord Brabant. The case study area is marked by the red circle

The chosen area has a surplus of approx. 255,000 tonnes of manure (cattle, pigs and hens/broilers) annually (200,000 tonnes of cattle and pig manure and 55,000 tonnes of poultry manure) that needs to be exported to other regions in the country. There are restrictions on applying organic waste on farm land.

The communities around Eindhoven started a project to define the possibilities of sustainable energy supply in this region. The biomass based energy potential of the area is estimated at 2.5 million GJ. This means that both the authorities (local and regional) and the farmers can stimulate the initiative for large scale digestion of manure.

Expected results

The assessments of the six case study regions have analysed the potential for biogas from centralised co-digestion in the region and the economic, environmental, and socio-economic impact of building such a plant at the chosen site.

The project work was based on the interaction between the national partners, their target group networks, and a core group of Danish experts, who carried out the assessment work. The activities carried out as well as the obtained results are and will be used to raise awareness among farmers, decision and policy makers, various biogas actors, and the large public about the potential and benefits of biogas from co-digestion in the respective regions.

The project is expected to have some long term effects related to the impact on the specific target groups, who should act further for the removal of the non technical barriers and the establishment of a biogas plant.

Two categories are particularly targeted. The first one represents the farmers and farmers' organisations, benefiting from improved conditions for manure handling and utilisation, easier compliance with agricultural and environmental requirements, and cost savings in fertiliser purchase.

The other category is represented by decision and policy makers, who should develop support schemes and operate changes in the legal framework in order to promote the development of biogas from anaerobic digestion on a large scale.

In conclusion, it is expected that the results of the project will be further disseminated, analysed and discussed by the national partners and the members of the target groups, in order to clarify the potential the incentives and the barriers of each case and for each target group.

It is also expected that the target groups will form the platform for the initiation of future policy initiatives for the development of biogas and that policy makers will subsequently initiate necessary legal changes to help removing the non-technical barriers. The established target group networks will form the organisational structure necessary for initiating specific biogas projects in these regions.

Promotion of Biogas for Electricity and Heat Production in EU Countries. (PROBIOGAS)

Assessed economic results from 6 European case studies, barriers and recommendations

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Abstract

The PROBIOGAS project is an EIE/Altener project co-funded by the EU Commission. It is accomplished by 11 European partners. The objective of the project is to stimulate heat and electricity production from biogas in EU countries. The aim is to assess economic, agricultural, environmental and energy aspects of biogas production by centralised co-digestion (CAD) in selected case study areas of six EU countries. The assessments clarify the incentives for implementation of CAD systems in those areas and help the identification and removal of existing non technical barriers.

Keywords

co-digestion, biogas, combined heat and power generation (CHP).

Background

During the 1980s and 1990s the centralised co-digestion plant concept (CAD) was developed in Denmark. The concept was subject to substantial international interest, as the technology turned out to be a multifunctional solution to a number of problems in the fields of energy, agriculture and environment. Not only did CAD plants prove to be technically viable, but in addition, at least under Danish conditions, also economically profitable. In 2002 a group of Danish scientists carried out a study in which external costs and benefits were quantified and monetised and included by application of socio-economic methods. For the first time all externalities that could be quantified were taken into account. The study concluded that the technology was both economically and socio-economically viable, and a favourable tool in green house gas reduction too. Similar studies were much in demand in many other European countries, but as calculations were carried out for Danish cost levels, results could not be transferred to the situation of other countries with no further notice. This is why the idea of PROBIOGAS developed; to model the performance of a CAD plant, hypothetically sited in livestock intensive case study areas in six EU countries.

Objectives

The overall aim is to support the development of heat and electricity production from biogas in EU countries by increasing the awareness about the CAD technology and its potential in each case study, in order to encourage decision makers and other biogas actors to remove existing barriers and to create favourable frameworks for implementation of CAD projects.

Approach

The project partnership consists of six national partners, from EU countries where biogas technologies need to be developed, and of a group of Danish biogas experts to carry out the assessment work. In each partner country, the Netherlands, Belgium, France, Spain, Greece and Ireland, a livestock intensive case study area was selected for assessment and the necessary data collected by national partners. For each case study, a target group network (TGN) was established, including farmers, organisations, companies, authorities and other biogas players. The TGN members are the main target group for dissemination of project results and may eventually form a platform for the future biogas project generation. They were actively involved in the project work from the start, throughout the introductory workshops and assisted national partners with data collection.

The assessment work should calculate the economic, socio-economic, and environmental effects of building a CAD plant in the respective case study areas, highlighting also the main incentives and barriers. The assessments used the existing model tools, developed in Denmark in 2002 [2], but are based on local figures about the amount and composition of manure and organic wastes, options for marketing heat and electricity, prices, climate data, agricultural practice regarding handling and utilisation of manure and waste etc. Based on this, a model plant was dimensioned, and the potential biogas production estimated as well as costs and sales, transportation, effects on nutrient utilisation and emissions of green house gases. The socio-economic part of the assessment, showing the impact of CAD from the society's point of view, was carried out as system analysis in a difference analysis, in which a hypothetical situation with a CAD plant was compared to a "business as usual" situation, without CAD. The assessments also address non technical barriers for the implementation of CAD and make recommendations for their removal. Although, the main part of the assessments is based on the concrete local premises and data, where possible and available, the calculation model was developed under Danish circumstances. For this reason, the results may not be regarded as feasibility studies ready for decision, as this was not the aim of this project. They must be followed by detailed technical, economical, and organisational planning before final decisions are made.

The assessment work was concluded in six national assessment reports, to be primarily disseminated to the TGN members as well as a Final Assessment Report [1], concluding all of them.

The CAD plant concept

The centralised anaerobic digestion plant (CAD) is a facility in which manure from a number of farms and organic waste from food processing industries is co-digested under anaerobic conditions to produce biogas (Figure 1). The digested substrate, frequently denoted digestate, is returned to the farmers and utilised as fertiliser in crop production. One possible option is to separate the digestate into a fibre and a liquid fraction before returning it to farmers. The produced biogas is used for electricity and heat production. The electricity is sold to the grid, and the heat is sold to heat consumers in the area.

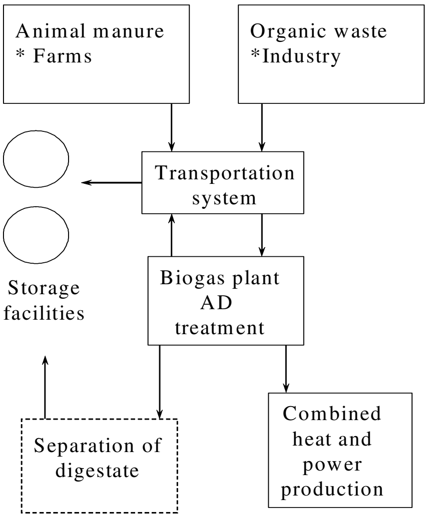

Figure 1. The CAD concept

Estimated treatment capacity and energy production

The project work involved six case studies:

- **The Netherlands**: Bladel, Region De Kempen, North Brabant
- **Belgium:** Province of Liege, Wallonia
- **France:** West Aveyron, Midi-Pyrénées
- **Ireland:** North Kilkenny
- **Spain:** Pla d'Urgell, Catalonia
- **Greece:** Tsikakis-Yiannopoulos pig farm, Sparta

The assessments were carried out according to the information collected and supplied by the national partners. The size of the model plants was determined by the amount of manure and organic wastes available. Table 1 shows the annual treatment capacity of the plant that can be built in each case. The table shows considerable differences in potential plant size. The largest plant size could be established in the Dutch case, and the smallest one in the Greek case. The daily treatment capacity varies form 93 to 600 tonnes per day.

Table 1. Treatment capacity and estimated energy production

	NL	B	F	IRL	SP	GR
Treatment cap. 1000 tonnes/year	220	75	44	53	168	34
Treatment capacity, tonnes/day	600	200	120	144	460	93
Biogas yield, mil m^3 CH_4/year	6,4	1,5	1,6	1,1	4,4	1
Biogas yield, m^3 CH_4/tonne	29	20	37	21	26	30
Electricity, 1000 MWh/year	23	7,9	5,9	4	16	3,7
Heat, 1000 MWh/year	34	7,9	7,5	4,6	23	5,2

The treatment capacity of the plant is determinant for the potential of biogas production. Thus the table also shows considerable differences in biogas production. However, the treatment capacity is by far not the only factor affecting the biogas production. The quality of the supplied manure and waste, their specific methane potential, the dry matter content and the ratio of different substrates within the biomass mixture are influencing the biogas production. Highest methane yields were estimated in the French and Greek cases, due to high ratio of organic wastes. Lowest methane yields were calculated for the Belgian and Irish cases, as waste application are highly restricted in these countries. The Netherlands has a particular situation, with highly restrictive legislation concerning utilisation of organic wastes, but with very high dry matter content in animal manure which, combined with co-digestion of chicken manure, with a high methane potential, gives a relatively high biogas potential, though no organic waste can be supplied. The table also illustrates the estimated production of electricity and heat, which is directly related with the level of biogas production.

Agricultural aspects and farmers benefits

When manure is digested, a higher nutrient utilisation can be obtained from it, when utilised as a fertiliser. The AD-mixture of organic wastes brings additional nutrients in accessible forms for the crops. Consequently, in many cases farmers would benefit from increased fertiliser values, when joining a CAD. On the other hand, in many cases farmers already have a large surplus of manure that is not allowed to be utilised on the respective farm area, and must be exported to other regions, according to national regulations. In those cases, some of the benefits from increased fertiliser value will be exported together with the surplus of manure to the crop farmers, who receive the digestate. These aspects are analysed in details for suppliers of manure and receivers of digestate in the national reports. Table 2 shows the estimated total economic savings in mineral fertiliser purchase for involved farmers.

Table 2. Total fertiliser savings, and cost savings in fertiliser purchase

	NL	B	F	IRL	SP	GR
Saved tonne N	413	73	61	30	198*)	44*)
Saved tonne P_2O_5	0	1,5	31	0	2*)	27*)
Saved tonne K_2O	0	65	35	0	2*)	27*)
Total savings fertiliser, 1000 EUR/year	308	82	79	21	160*)	76*)
Average savings per hectare, EUR/year	25	27	53	5	-	-

*) Potential benefits as a result of the CAD, but not utilised

Table 2 shows that considerable cost savings may be obtained by farmers if a CAD plant is established. In most cases the largest benefits are found among receivers of surplus manure. In the Spanish and Greek cases the surplus is not redistributed and utilised. For that reason large fertiliser values can not be utilised.

The economy of the farmers is affected by other than fertiliser aspects. In all cases, manure has to be stored for some time in order to optimise the application and utilisation. When a CAD is involved, digested manure is afterwards stored as liquid manure (if not separated), in most cases for six months or more. Manure storage may increase the costs, especially if the previous system was partly based on solid manure, which is normally cheaper to store. Also manure spreading costs are affected, as often more manure must be spread due to the waste supplied. These costs may be balanced by increased fertiliser values and higher nutrient utilisation. Finally, in some cases the farmers face considerable transportation costs, if they need to export the surplus of manure. In the assessments these costs are supported by the CAD and the farmers benefit from cost savings for long distance transportation of their surplus manure. How participating farmers are economically affected is showed in Table 3.

Table 3. Economic benefits for farmers (manure suppliers) in national 2005 prices, 1000 EUR/year

1000 EUR/year	NL	B	F	IRL	SP	GR
Manure storage	0	-7	-7	-14	0	0
Manure spreading	16	-11	-1	-22	0	0
Fertiliser value *)	0	17	16	40	0	0
Long distance transportation	1054	22	0	0	0	0
Total cost savings	1070	21	8	4	0	0

*) Achieved by farmers in the local area. Potential fertiliser values for crop producing farmers in other regions are not included in this table

The assessments assumed that the behaviour related to utilisation of digestate as fertiliser of the Spanish and Greek manure suppliers will not change much, compared to the situation without CAD. For that reason they are not likely to benefit much from the CAD with respect to fertiliser value and handling of manure, and the potential benefits mentioned in Table 2 will not be realised. In the other cases the farmers will benefit though to highly variable extent. In most cases farmers face increased costs in manure storage and spreading because the systems switch from partly liquid/solid to entirely liquid. In addition, a larger volume of manure has to be spread, which increases the spreading costs somewhat. However, this cost increase is more than balanced by improved fertiliser value and cost savings in transport costs when exporting surplus manure to other regions. This is especially true in the Dutch case, where it is assumed that the CAD supports the long distance transport and redistribution of surplus manure.

Economic performance of the CAD plant

The dimensions of the CAD plant are determined by the needed treatment capacity. Investment costs, assessed on the basis of the model plants [2] are showed in Table 4.

Table 4. Investment costs mill EUR, 2005 national prices

Mill. EUR	NL	B	F	IRL	SP	GR
Capacity tonne/day	**600**	**200**	**120**	**144**	**460**	**93**
Biogas plant	6,1	3,9	4,2	3,7	5,3	2,7
CHP facility	2,1	0,5	0,5	0,4	1,3	0,3
Total investment costs	8,2	4,4	4,7	4,1	6,6	3,0

Total investment costs range from 3-8 mill. EUR. The French case is relatively expen-

sive due to the need, in this case, for a relatively long pipeline for transmission of biogas.
The economic performance of the CAD depends not only on the biogas yield, but also of a number of key preconditions. Some of the most important of these are presented in Table 5.

Table 5. Important preconditions, national price level

	NL	B	F	IRL	SP	GR
Electricity price, EUR/KWh	0,06	0,11	0,14	0,07	0,07	0,07
Heat Price, EUR/MWh	0	30	25	20	0	0
Treatment fees, EUR/tonne	0	4,8	30	13	27	120

The importance of the mentioned parameters will occur in the following paragraphs. The economic performance of the CAD system contains costs from manure transport to and from the plant, storage of digested waste, cost and sales of heat, electricity and treatment fees resulting from the operation of the plant. In the Irish case costs for post separation are included. Costs and revenues from the biogas production are presented as a net result of the biogas plant in Table 6 below. This table shows that four of the estimates showed positive net results of the biogas plant itself. Where positive net results could not be achieved (Netherlands and Ireland) it is due to very restrictive regulations on waste application, low electricity prices, and especially in the Dutch case, no market for the heat is found. This is also true for the Spanish and Greek cases. Only in two situations transport and other costs could be covered.

Table 6. Economic performance of the CAD system, 1000 EUR/year, average national 2005 prices

1000 EUR	NL	B	F	IRL	SP	GR
Capacity, tonnes/day	600	200	120	144	460	93
Transport	-1540	-209	-133	-111	-595	-45
Waste storage	0	-19	-7	-22	-1	-0,1
Separation	0	0	0	-40	0	0
Net result biogas plant	-24	88	486	-53	197	129
Profit	-1564	-140	346	-226	-399	84

As mentioned, the Dutch case is disadvantaged by restrictive legislation regarding the organic waste supplied to the plant, low electricity price, and no market for the heat. It is an advantage of this case that the dry matter content in manure is high, so in spite of the mentioned disadvantages, the net result of the plant is close to balance. The Dutch case includes high transport costs, as it is assumed that the entire manure amount is afterwards transported a long distance, to areas, where it is allowed to be used as a fertiliser.

The Belgian case is disadvantaged by a relatively low biogas production due to relatively low waste supplies. On the other hand it is favoured by an attractive electricity price, and a market for heat.

The French case seems to have almost optimal conditions, relatively ample waste supplies, and a relatively high electricity price and a market for the heat.

The Irish case is disadvantaged by heavy restrictions on waste supplies and a poor electricity price.

The Spanish case has a low electricity price, no heat market and needs higher amounts of good quality organic waste. The Greek case also has a low electricity price and no heat market, but has ample organic waste supplies and very high treatment fees, so the CAD system turns out profitable in this case.

The mentioned disadvantages may be seen as non technical barriers that must be removed before an enlargement of plants is likely to take place. Several barriers are common to more than one of the case studies. Most important non technical barriers were found to be electricity prices at unattractive levels, restrictions on waste supplies, lack of heat markets, and legal, administrative barriers, and lack of information. Non technical barriers are addressed in more detail in the national reports.

Potential, barriers and recommendations

From table 6 and the explanations above it appears that five of the case studies have one or several disadvantages that seriously affects the profitability of the CAD system. In fact, the potential of the analysed case studies is limited by the mentioned disadvantages or barriers. Only the French case seems in many respects to have excellent preconditions. Three important parameters should be accentuated; the French plant is favoured by a relatively attractive electricity price, a market for heat production, and the possibility to supply sufficient organic waste in order to produce enough energy to make the CAD system profitable. Methane yields are high even compared to existing Danish plants. Sufficient waste gives significantly different business opportunities than if no waste can be supplied, as methane production is easily more than doubled by waste supplies of good quality. A heat market is also important as approx. 50% of the energy production is found in the form of heat. So given optimal preconditions as in the French case, the potential of a CAD system from both economic and socio economic points of view is:

- The CAD system is profitable even when transport costs are included
- It is very close to socio-economic break even
- Farmers benefit economically
- Reduced nitrate leakage of 15 tonnes N per year
- GHG reduction of 186 kg CO_2 eqv. per tonne input
- Cost efficiency of GHG reduction of 26 EUR per tonne CO_2 eqv.

Only one parameter in disfavour of the French case is the relatively small size of the plant. By additional treatment capacity per unit treatment costs are reduced and economic performance further improved. On the other hand, the system must be optimized according to the possibilities to sell heat, procure organic waste and transport distances. Table 7 attempts to explain the net result of the biogas plant by showing to what extent each case has optimal conditions. In the evaluation, Danish preconditions are inserted

Optimal condition	++
Good conditions	+
Poor conditions	-

Table 7. Evaluation of key preconditions

	DK	NL	B	F	IRL	SP	GR
Electricity price	+	-	++	++	-	-	-
Heat market	++	-	+	+	+	-	-
Waste allowed, use of digestate	++	-	+	++	-	+/-	++
Administrative procedures, authorities helpful	++	-	+/-	+/-	-	-	-
Net result biogas plant		-24	88	486	-53	197	129

The table indicates that the possibility to use sufficient organic waste is the most important parameter.

So what should be done?

Danish experience showed that establishment of CAD plants requires positive involvement from a range of individuals, organisations, companies, local and national authorities and the political system. It is crucial that the political system provides a legislative framework that allows CAD projects to be realised. Except perhaps the missing heat markets, all the above mentioned most important barriers may all be removed by national initiatives in each of the participating countries. This could be done by changing regulations, introducing green electricity bonus and information of farmers, companies and authorities of the potential benefits from the society point of view that are provided by the CAD technology, as illustrated in the assessed results of the PROBIOGAS project.

Electricity prices at unattractive levels. The obtainable electricity prices in the Netherlands, Ireland, Spain and Greece are very low compared to Belgium and France, but also to other European countries, where the numbers of biogas plants are increasing. It is recommended that a green electricity bonus is introduced in the mentioned countries, in order to encourage heat and electricity production from biogas.

Restrictions on waste application. In The Netherlands and Ireland it is almost impossible to supply organic waste to a CAD, due to restrictive legislation, which makes co-digestion a rather impossible option. In Spain and Belgium legislation on waste application is also restrictive. It is necessary that legislation on this issue becomes more permissive, similar to the Danish model, as organic waste supply is crucial for the economy of the plant, not least by boosting the methane yield, providing income from treatment fees and increased fertiliser value. If handled properly, co-digestion of suitable organic wastes proved to be advantageous from many points of view, according to Danish experience.

Lack of heat markets. In the cases of The Netherlands, Spain and Greece no heat markets are found, which is a serious problem, as a large part on of the energy production can not be utilised and the income related to it cannot be obtained. It is recommended to encourage alternative ways of marketing the heat, for industrial purposes for example. If this is not an option, other than combined heat and electricity production from the biogas should be considered, for example in the Dutch case distribution throughout the natural gas grid, and in other countries vehicle fuel could be considered.

Legal, administrative barriers and information. The realisation of a CAD plant is very complex, and involves many individuals, companies and authorities, and will get in touch with many fields of regulation. For this reason, in countries where CAD plants are not commonly known, it is recommended to give specific information about the potentials of the technology to relevant authorities, institutions, business branches and the public.

In the Danish context the development was favoured by the fact that markets for the energy was provided. As mentioned, district heating is widespread in Denmark, and as heat from biogas is not energy taxed heat may be sold at attractive prices for heat consumers. Electricity market is provided by purchase obligations and a fixed subsidised electricity price
Most possible organic waste recycling was for long the established Danish policy. Landfilling of organic waste is not allowed, and waste is subject to heavy tax when incinerated. Thereby the perfect incentive structure is created to lead suitable waste streams to be recycled via CAD plants. In fact this is very important from both a business and a society point of view, and shows that where economic and environmental benefits go hand in hand renewable energy sources may succeed.

Farmers' involvement in CAD projects is important for the performance of the system. Not only do they supply the raw manure, they also receive the digested manure. It is important that they understand and accept the importance of supplying manure of high quality, which means fresh and with high dry matter content. Earlier, the motivation for Danish farmers to join CAD projects was mainly the access to manure storage tanks provided by the CAD-company, as they since 1987 need a storage capacity from 6-9 months. But in recent years the motivation has increasingly been directed to the distribution of surplus manure, which is required if manure from livestock production exceeds the land needed for spreading. So in fact, Danish farmers face a legislative push to seek cost efficient solutions for their environmental problems caused by manure from livestock production. This is also the case for farmers in some of the six case studies, but apart from the Dutch farmers, it seems not the same extent as Danish farmers.

Most Danish CAD plants are organized as cooperatives. As cooperatives are widespread in Danish agriculture, the type of organisation seemed a natural choice for organising CAD plants in the Danish context. But it also means that farmers do not withdraw large profits from the CAD companies. Their interests are found in the externalities, the derived cost savings in manure storage, transport and spreading, again coincident economic and environmental benefits

It was a demonstration programme launched in 1988 that accelerated the technology development and enlargement of plants in Denmark. The demonstration programme proved a good way to get started, which may also be the case in the countries participating in the PROBIOGAS project. The Danish demonstration programme provided investment grants for new plants and funding for special research tasks. The demonstration programme was supported by a monitoring programme in which the gained experience was collected, analysed and communicated to farmers, plant managers and owners, companies, authorities and the political system.

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Case studies assessment results: Environmental externalities of centralized co-digestion

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Introduction

Environmental hazards related to animal manure management are greenhouse gas emission, ammonia emission, odor and nitrate leaching.

Green House Gases (GHG) can be efficiently reduced by processing manure in a biogas plant. There is a risk the anaerobic digestion of manure will increase ammonia emission during storage of fermented slurry but this risk can be mitigated by cheap and simple covering the stored manure [1]. Ammonia emission from applied slurry is not affected by fermentation of the slurry [2]. Odour may be reduced by biogas production especially if the biogas plant is properly build and emission of gases from the plant reduced with air filters etc. Leaching and erosion losses of nitrogen and phosphorous can be reduced due to more efficient use of nitrogen in manure and a better distribution and use of manure plant nutrients.

In this project the objective is to assess the direct effects of the biogas treatment on environmental hazards related to livestock farming. The direct effect are primarily a reduction of the emission of the greenhouse gases. Anaerobic digestion of animal manure in a biogas plant has been shown to reduce methane and nitrous oxide [3]. Further we have developed algorithms that can be used globally to assess this effect.

A sensitivity analysis of the reduction in methane emission as affected by treatment in biogas digesters was carried out for pig production in Belgium and Spain. The analysis shows the reduction in methane emission as affected by interaction of climate, manure management and anaerobic digestion. The article also presents the reduction in GHG emission as affected by anaerobic digestion in the six cases from the countries involved in this study i.e. Belgium, The Netherlands, Ireland, Greece, Spain and France.

Method

Methane emission from animal slurry systems is calculated using the dynamic models of Sommer et al. (2004) [3]. In Europe, cattle and pigs are either housed throughout the year or housed during winter with summer grazing. During housing, excreta are mostly stored for a period in house, a period before being transported to an outside storage tank or heap, and then later applied to arable soil. In accordance with this manure handling system, the model contains housing, storage and a field compartment. Calculations are based on excretion of volatile solids (VS d^{-1}), and manure management and storage time is defined by information collected in the surveys in Belgium, the Netherlands, Ireland, Greece, Spain and France.

The model considers *VS* to be a main driving variable for greenhouse gas emissions from animal manure. Thus, CH_4 emissions are related to the content of degradable *VS*, as modified by residence time and temperature inside the animal house and during outside storage.

$$F(T) = VS_d \times b_1 \times \exp(\ln A - E \times (1/RT)) + VS_{nd} \times b_2 \times \exp(\ln A - E \times (1/RT)) \qquad (1)$$

In Eq. (1), F is the emission rate (kg CH_4 d^{-1}), b_1 and b_2 are rate correcting factors (no dimensions), A is the Arrhenius parameter (kg CH_4 $tonne^{-1}$ VS h^{-1}), E the apparent activation energy (J mol^{-1}), R the gas constant (J K^{-1} mol^{-1}), and T the temperature (K). The parameters used in the calculations are presented in the article of Sommer et al. (2004) [3]

The model can not assess the methane emission from solid manure. Consequently, this emission is calculated using the tier 2 model presented by IPCC [4].

$$F = VS \text{ x } B_0 \text{ x } MCF \text{ x } 0.67 \qquad (2)$$

F is the annual emission kg $year^{-1}$, B_0 is the maximum methane production capacity (0.24 m^3 kg VS for cattle) and *MCF* is the methane conversion factor typical for the climate region. The involved countries are in this model considered to be in the agro ecological region of Western Europe and MCF is 2%.

Air temperature is providing a very fine estimate for slurry temperature as shown in the article of Hansen et al. (2006) [5]. Therefore, the temperature used to estimate CH_4 emission from slurry stored in house is related to the air temperature in the housing systems in the regions for which there is provided activity data about livestock and manure management. Ambient air temperature is used to assess the temperature of outside stored slurry. In the biogas plant the anaerobic digestion will reduce the content of digestible VS, and consequently the CH_4 production during storage, which in most countries will be in outside storage tanks.

The N_2O model developed by Søren O. Petersen [3] predicted that N_2O production from untreated slurry was an order of magnitude higher than from anaerobic digested slurry. The results of the model calculation is in accordance with results from a laboratory study where denitrification from untreated and digested slurry corresponded to, respectively, 17% and 1.7% of TAN applied to soil [6]. This effect is due to reduction of digestible VS in slurry when treated anaerobically in the biogas plant. In the field microbial transformation of VS consumes oxygen, therefore a high content of VS will reduce oxygen content in the soil to which slurry is applied. The N_2O production takes place in an environment with low content of oxygen; therefore reducing VS of slurry will reduce N_2O emission from the applied slurry. In this study a N_2O reduction factor is used (Table 1). This simple model is the best at present when assessing the potential reduction of N_2O at regional scale. It is known that the emission will be affected by local conditions, and studies are needed to achieve this information.

Table 1. Factor for calculating the reduction in N_2O emission from animal slurry and organic waste applied in the field, the biomass being treated in biogas plants. Factors are assessed using the information in the article [3]

Biomas	Reduction factor kg N_2O-N per kg $N_{biomass}$
Cattle slurry	0.0039
Pig slurry	0.0048
Waste	0.0048

Results

Sensitivity analysis Spain and Belgium

A Belgian and Spanish sensitivity analysis has been carried. It is assumed that pigs excrete 1 tonne VS per day on slats, slurry is stored inside for 14 days and the outside stores is emptied in April. In Belgian the temperature in the pig houses is relatively constant at 20°C whereas in the Spanish pig production systems the temperature in the houses varies and is high during summer (30°C) and low at winter (9°C). Outside the slurry will be stored at temperatures from 1 to19°C in the Belgian sensitivity test and in the Spanish sensitivity test at 2 to 27°C. In consequence to the higher temperatures methane emission from untreated pig slurry is higher in the Spanish scenario than in the Belgian scenario (Figure 1 A & B). The effect of fermentation reducing VS in the stored slurry stored outside is higher in Spain than in Belgium (Fig. 1 A & B), because the higher temperatures in Spain will give a higher methane production potential of the digested slurry VS compared to the situation in Belgium.

The effect of daily flushing the slurry out of the pig house was assessed in the Spanish scenario. It is seen that removing the slurry from a warmer environment in house to a colder outside is reducing the methane emission (Figure 1 C solid line). The model calculation also show that combining frequent emptying the slurry channels in house and anaerobic digestion of the pig slurry in a biogas plant will give a large reduction in methane emission.

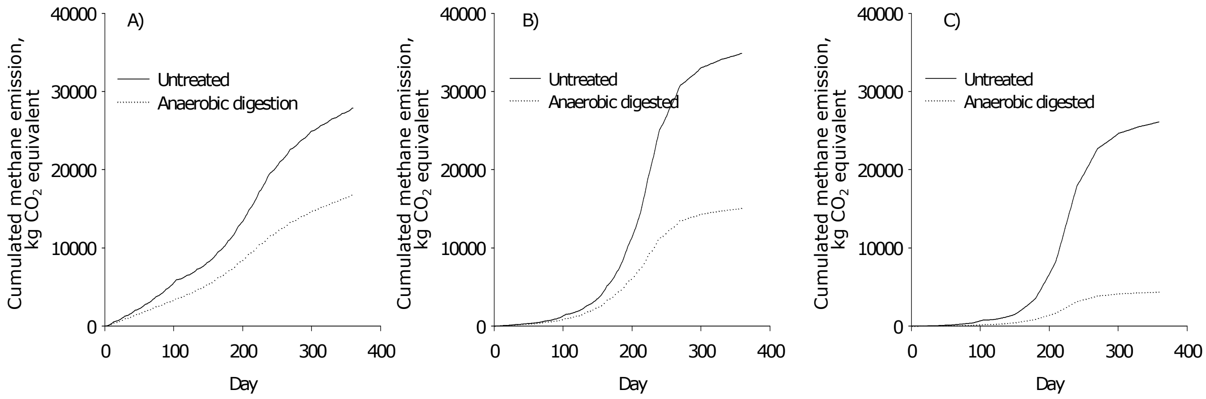

Figure 1. Sensitivity analysis of the methane emission as affected by treating pig slurry in an Anaerobic digester before storing the slurry in outside stores. Each day 1 tonne VS is deposited in the slurry channels in the pig house. **A**) climatic conditions as in the Belgian and **B**) climate in the Spanish case are chose, In both analysis the slurry channels in the house are emptied twice a month and outside slurry store in April. In **C**) climatic

conditions are as in the Spanish case, slurry channels are emptied every day and outside slurry store are emptied in April.

Case studies from the six countries involved in the study

Anaerobic digestions of solid manures have no effect on the emission of methane or may even increase the emission. The solid manure that in the traditional system is stored aerobically with a low emission of methane will after treatment in the centralised biogas plants (CAD) be stored anaerobically with a higher potential for methane emission, because the digesters are feed with liquid feedstuff and the solid is mixed into the liquid. In consequence, the emission of methane will increase despite the reduction in digestible volatile solids in the manure. Thus, in the Belgian and the Irish case the digestion of solid manure from dairy and beef cattle and horses is increasing methane emission (Fig. 2).

In the case from The Netherlands a very high amount of pig and cattle slurry was treated in the CAD, a scenario giving a high reduction in GHG emission (Fig. 2). In the Belgian and Irish case the amount of slurry treated was relatively low; therefore the reduction in methane emission is lower than in the Dutch case. In the Irish case the cattle is grassing during the summer period and no manure is stored during this period, thus, in the period with high temperatures no slurry is stored in outside stores and methane emission from stored liquid manure is low. In consequence anaerobic digestion will not reduce methane emission significantly.

There is no assessment of the effect of feeding the anaerobic digester with poultry manure. No reliable factor for calculating methane and nitrous oxide emission from stored chicken manure could be found in literature and a calculation of the effect of digestion would be very hypothetical.

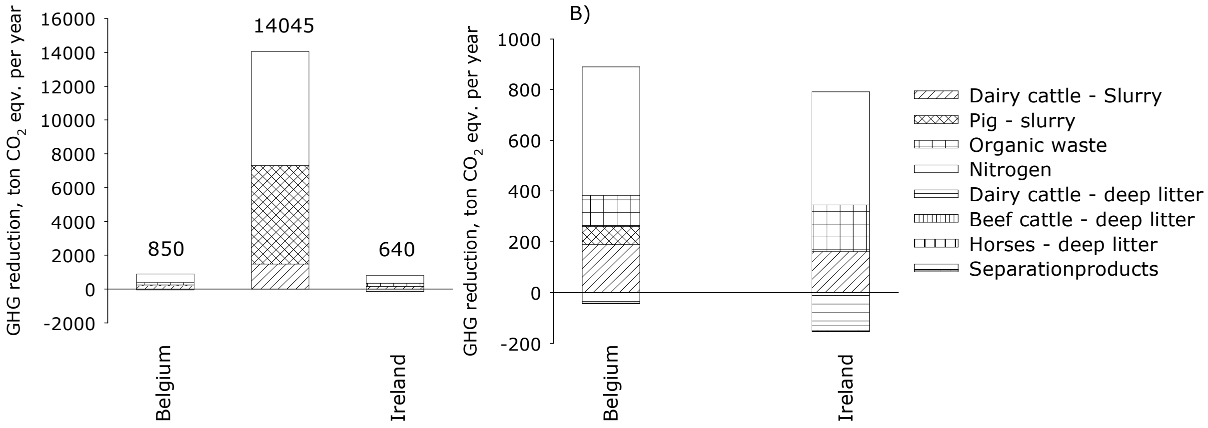

Figure 2. Reduction (positive) and increase (negative) emission of nitrous oxide and methane as affected by introducing anaerobic digestion in livestock manure management in Belgium, The Netherlands and Ireland. The change in GHG emissions are presented as CO_2 equivalents per year and the total effect is giving at the top of each bar (CH_4 corresponds to 21 and N_2O to 310 CO_2 equivalents [7]). Note different scales on the Y-axes in A) and in B).

Anaerobic digestion of liquid animal manure will significantly reduce nitrous oxide emission from liquid manure applied in the field. The effect of the treatment is large in the six cases presented in this study. Nitrous oxide is a GHG with a high climate warming effect therefore when expressed as CO_2 eqv. the reduction is contributing about half of the GHG reduction potential of the anaerobic digestion (Fig. 2&3), Greece is an exception, because of the relatively low nitrogen content of the organic waste.

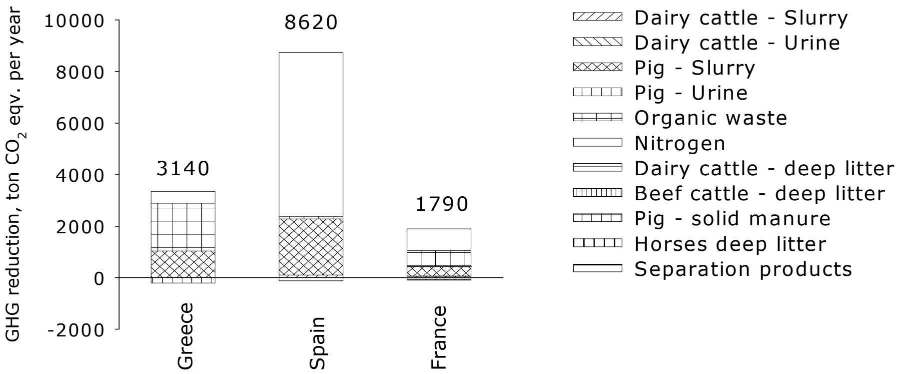

Figure 3. Reduction (positive) and increase (negative) emission of nitrous oxide and methane as affected by introducing anaerobic digestion in livestock manure management in Greece, Spain and France. The change in GHG emissions are presented as CO_2 equivalents per year, and the total effect is giving at the top of each bar (CH_4 corresponds to 21 and N_2O to 310 CO_2 equivalents [7]).

In the Greek case manure from sow houses are separated by scraping the solids to a solid manure store and the liquid is transferred to a lagoon. The slurry from the other pig houses is separated in a liquid and solid fraction outside the animal house, the solid fraction is stored in the solid manure store and the liquid in the lagoon. Treating the solid manure and solid separation products in an anaerobic digester will increase methane emission. Of the three Mediterranean countries Spain with the highest production of liquid manure show the largest reduction in GHG gas emission as affected by anaerobic digestion. In France the cattle manure is managed as deep litter or solid manure, and as mentioned anaerobic digestion of this manure is not reducing methane emission.

Conclusion

The Spanish and Dutch cases have the largest reduction in GHG emission due to anaerobic digestion of large amounts of animal slurry in the Biogas Plant. In the Irish case GHG gas emission from untreated animal manure is low; as a consequence of a low GHG emission from untreated manure. In the cases from Belgium, Ireland and France anaerobic digestion of solid manure or solid separation products cause an increase in GHG emission from these products. Except for the Greek case the anaerobic digestion reduces nitrous oxide emission from field applied slurry significantly. A scenario analysis is indicating that the effect of combining anaerobic digestion of liquid manure with anaerobic digestion will reduce methane emission significantly

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Socio-economic aspects of centralized co-digestion

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Abstract

PROBIOGAS[1] is an EIE/Altener project co-funded by the EU Commission. The project is carried out by 11 European partners in collaboration, and the project objective is to stimulate the utilization of centralized biogas co-digestion technology in EU countries as basis for heat and power generation. The aim is to assess economic, agricultural, environmental and energy aspects of biogas production based on the concept of centralized co-digestion (CAD). Case studies covering six selected areas and EU countries are carried out. The present paper summarizes the PROBIOGAS main socio-economic results which include quantification and monetization of external aspects. Main focus in this presentation is given to the achievable green house gas (GHG) reductions and reduction costs by utilizing centralized co-digestion.

Keywords

Biogas co-digestion plants, socio-economy, externalities, greenhouse gas emission reduction, biogas, combined heat and power generation (CHP).

Introduction

The socio-economic analysis looks at the CAD system from the point of view of the society at large. Therefore all consequences of the CAD system in any sector of society should in theory be taken into account, - including externalities.

Conventional economic analyses and corporate investment analyses of projects do not take the so-called externalities into account (Lesourne, 1975). Externalities, or external effects, imply neither expenses nor income for the corporate or private investor. However, a project may inflict burdens or contribute gains for the society relative to the reference activity, which must be taken into account when evaluating a project from the point of view of the society. A socio-economic analysis looks at the project or activity in question including externalities.

Biogas projects have implications not only for the agricultural sector, but also for the industrial and energy sectors. For the environment, mitigation of greenhouse gas (GHG) emissions and eutrophication of ground water etc. are important external effects. In this study, a considerable effort was put into the assessment of these biogas scheme externalities.

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[1] PROBIOGAS: Promotion of Biogas for Electricity and Heat Production in EU Countries - Economic and Environmental Benefits of Biogas from Centralized Co-digestion.

The present paper summarizes the PROBIOGAS main socio-economic results which include quantification and monetization of external aspects. Case studies covering six selected areas and EU countries have been carried out. Results on the annual socio-economic costs and benefits for each case study are presented, and furthermore the calculated green house gas (GHG) reductions and reduction costs for the six case studies are presented.

Objectives and analytical approach

The objective of the analysis is to estimate the socio-economic feasibility of best practice centralized CAD technology via the assessment of the technology applied in cases covering six selected areas and EU countries. Furthermore, for each of these very different cases, the objective has been to estimate consequences for GHG emissions and to estimate GHG emission reduction costs associated with using this CAD technology.

The analysis is carried out as a difference project analysis, in which an alternative activity is compared with its reference activity. The socio-economic evaluation of the alternative, the CAD system, relative to its reference or 'business as usual' involves quantification and monetization of impacts of the alternative for a number of reference activities affected by the CAD system.

An analytical approach has been applied where the socio-economic calculations are differentiated into levels, where each new level takes into account still more of the external effects related to the CAD system. Four levels are included in the analysis, termed Result 0,1,2,3, where the base level do not include externalities and the analysis at a higher level includes all effects of lower levels, as illustrated in Table 1.

Table 1 Socio-economic aspects included in the different levels of the analysis.

Level of analysis:	**Result 0**	**Result 1**	**Result 2**	**Result 3**
Aspects included:				
Energy and resources:				
Value of energy production (biogas, electricity)	R0	R0	R0	R0
Capacity savings related to the natural gas grid	R0	R0	R0	R0
Security of energy supplies and political stability issues				(R3)
Resource savings (energy and nutrients)				
Global balance of trades				
Increased road/infrastructure costs				
..				
Environment				
Value of GHG reduction (CO_2, CH_4 and N_2O)			R2	R2
Other emissions (SO_2, NO_x,..)				
Savings related to organic waste treatment and recycling		R1	R1	R1
Value of reduced N-eutrophication of ground water:			R2*	R2*
Value of reduced obnoxious smells				R3
..				
Agriculture				
Storage, handling and distribution of liquid manure:		R1	R1	R1
Flexibility gains at farms				
Value of improved manurial value (NPK)		R1	R1	R1
Veterinary aspects				
..				
Investments and O&M-costs:				
Investments. Biogas Plant	R0	R0	R0	R0
O&M of Biogas Plant , incl. CHP unit for process heat	R0	R0	R0	R0
Investments and O&M for liquid manure transport	R0	R0	R0	R0
..				
Other aspects				
Employment effects				
Working environment aspects, helth and comfort				
..				

* Data for the Danish case is used.

Only the aspects marked with 'R' in Table 1 are taken into account in the present case studies. All remaining issues have not been quantified and monetised for the analysis due to lack of data for the case. Furthermore, the list of aspects shown in Table 1 does of course not exhaust the spectrum of consequences and externalities that in principle ought to be taken into account. However, patterns of consequences 'upstream and downstream' of an activity are often very difficult to access, and generally a number of 'cut offs' in the level of detail of the analysis have been done.

Results presented below are based on 'Result 3' assumptions, - thus taking all quantified externalities into account.

General socio-economic assumptions

The socio-economic analyses are based on a number of general assumptions. Important in particular are assumptions made concerning future fuel prices, covering the period analyzed 2006-2025. The fuel prices assumed are based on forecasts from the International Energy Agency`s (IEA) published in World Energy Outlook (Oct. 2004), and modifications made by the Danish Energy Agency (2006) for these to comply with the actual (historical) prices seen since publication. Details about energy price forecasts are found in the national reports.

Identical reinvestments are included when the technical lifetime of an investment reach below year 2025. Termination values of investments or reinvestments with lifetimes going beyond the time horizon 2025 are determined via annuity calculation.

All prices in the socio-economic analysis are expressed as so-called factor-prices that do not include taxes, subsidies etc. A socio-economic rate of calculation of 6% p.a. is used, and the analyses cover the period 2006-2025. Values are given in year 2005 prices.

CAD energy production

The CAD plant is combined with a CHP-plant (Combined Heat and Power) that utilizes all the biogas produced. Energy output from the facility is electricity and heat in amounts as shown in **Table 2**.

Table 2 Treatment capacity and estimated energy production.

	F	IRL	SP	GR	B	NL
Treatment capacity: 1000 ton /year	44	53	168	34	75	220
Treatment capacity: ton /day	**120**	**144**	**460**	**93**	**200**	**600**
Biogas yield: mil m3 CH4/y	1,6	1,1	4,4	1	1,5	6,4
Biogas yield: m3 CH4/t	**37**	**21**	**26**	**30**	**20**	**29**
Electricity: 1000 MWh/y	**5,9**	**4**	**16**	**3,7**	**7,9 ***	**23**
Heat: 1000 MWh/y	**7,5**	**4,6**	**23**	**5,2**	**7,9**	**34**

* Green certificates included – see Belgian national report for further explanation

The assumed socio economic sales prices for electricity as levellized average covering the period 2006-2025 is 34 €/MWH$_{el}$ (excl. CO_2 cost content). This is based on the forecast Nordpool price development (Danish Energy Authority, June 2006) minus an estimated CO_2-price element. The price of heat has been assumed constant (in fixed 2005-prices) at a socio-economic price of 25€/MWh$_{heat}$.

In three cases the plants are unable to sell their heat production. This is the case for SP, B and NL.

GHG emission reduction

The green house gas emissions substituted as consequence of introducing the CAD alternative in each of the cases are quantified explicitly as shown in Table 3 below.

Table 3 Estimated green house gas reduction in each of the case studies**.**

	F	IRL	SP	GR	B	NL
Per day treatment capacity, tons	**120**	**144**	**460**	**93**	**200**	**600**
Ton CO2 or CO2 eqv.						
Electricity sales	**3575**	**1856**	**10823**	**2320**	**1762**	**15386**
Heat sales	2637	1217	0	0	920	0
NPK substitution	622	299	1909	453	742	3932
Transport fuel	-99	-32	-454	-44	-201	-531
Total from energy substitution	**6735**	**3340**	**12278**	**2729**	**3223**	**18787**
CH4, Ton CO2 eqv						
Animal manure	336	6	2163	840	219	7308
Organic waste	630	183	105	1848	122	0
CHP plant, unburnt	-378	-273	-1134	-252	-226	-1575
Total from reduced CH4 emissions	**582**	**-78**	**1124**	**2436**	**115**	**5726**
N2O, Ton CO2 eqv.						
Manure and waste	**839**	**446**	**6365**	**465**	**507**	**6737**
Total reduction in ton CO2 eqv	**8155**	**3709**	**19767**	**5630**	**3845**	**31250**
CO2 reduction, ton CO2 eqv/ton biomass	**0.186**	**0.071**	**0.118**	**0.166**	**0.051**	**0.142**

Considerable differences are seen in the estimates for GHG reduction among the plants. This is partly due to differences in energy production. In the Belgium and Ireland cases relatively low methane production is obtained due to the quality of the waste supplied. Waste admixture is not only important for the direct economic performance of the scheme, but also for the biogas production and GHG emission reduction, and thus also indirectly for the socio economic performance. Furthermore, high GHG emission reduction is found when manure systems in the reference are mainly liquid systems. However, when solid manure and deep litter not liquefied in the reference are liquefied in the alternative biogas situation, the afterwards storage of degassed manure is more or less anaerobic, causing an CH_4 emission increase in comparison with traditional storage of solid manures. For these reasons the estimated GHG reductions are relatively lower in the Belgian and Irish cases.

CO_2eq emission reductions achieved are monetized via an estimated (constant) market value of CO_2 emission allowances covering the period 2006-2025. This estimated value is 20EUR/ton CO_2eq.

Annual costs and benefits

An overview of the annual costs and benefits entering the socio-economic calculation is given in **Table 4**. All quantified and monetized consequences available for the present analysis are included in the overall socio-economic results shown in **Table 4**. More detailed results are found in the national reports.

Table 4. Annual socio-economic costs and benefits for the CAD alternatives, levellized annuities.

	F	IRL	SP	GR	B	NL
Per day treatment capacity, tons	**120**	**144**	**460**	**93**	**200**	**600**
Methane yields, m3 CH4/ton biomass	37	21	26	30	20	29
Costs:			**1,000,000 Euro /Year**			
Investments:						
-Biogas plant	0.389	0.388	0.493	0.249	0.359	0.574
-CHP plant	0.049	0.038	0.109	0.025	0.044	0.185
Operation and maintenance						
-Biogas production	0.284	0.285	0.413	0.180	0.278	0.566
-Vehicle fuel	0.013	0.004	0.061	0.006	0.027	0.071
-Transport costs (excl. fuel)	0.104	0.137	0.456	0.036	0.132	1.374
Sum	**0.839**	**0.852**	**1.532**	**0.496**	**0.840**	**2.770**
Benefits:			**1,000,000 Euro /Year**			
Energy production						
-Electricity sales	0.190	0.136	0.479	0.126	0.355	0.785
-Heat sales	0.188	0.093	0.000	0.000	0.088	0.000
Agriculture						
-Storage and handling of manure	-0.014	-0.036	0.000	0.000	-0.025	-0.037
-Improved fertilizer value (NPK)	0.016	0.021	0.160	0.076	0.087	0.308
-Transport savings at farms	0.000	-0.027	0.000	0.004	-0.006	1.066
-Veterinary aspects (not quantified)						
Industry						
-Savings in organic waste treatment	0.182	0.235	0.104	0.278	0.062	0.000
Environment						
-Value of green house gas reduction	0.165	0.096	0.399	0.114	0.078	0.631
-Value of reduced Nitrogen losses	0.051	0.038	0.166	0.037	0.061	0.347
-Value of reduced obnoxious odours	0.017	0.017	0.083	0.008	0.026	0.108
Sum	**0.795**	**0.573**	**1.391**	**0.643**	**0.726**	**3.208**
Socioeconomic surplus:	**-0.044**	**-0.279**	**-0.140**	**0.147**	**-0.114**	**0.438**

It is seen from **Table 4** that two of the cases are found to be socio-economic profitable based on the assumptions given. The profitability depends on results for a number of parameters, which may point in different directions, thus indicating that preconditions may be further optimized. The Dutch case is found to be highly socio-economic feasible. Reasons for that are that it is a very large plant taking advantage of economies of scale, and furthermore, that the manures supplied to this plant have very high dry matter contents, which gives a relatively high energy production even with no waste supplied.

Second most profitable scheme is the Greek case which benefits largely from plenty of waste. The French case is close to the break-even point and has in general good preconditions, - but it is a relatively small plant. The Spanish and Belgian cases are socio–economic non-profitable based on the assumptions made, and respectively of about 10% and 15% increased income (or cost reductions) are required for these schemes to reach socio-economic break-even. The lowest profitability is found in the Irish case, mainly because energy production is low due to the restrictions on waste supplies.

There are large potentials for increasing fertilizer values, and cost savings for farmers, and results would improve if all heat produced was utilized.

GHG emission reduction costs

Results from the socio-economic case studies may furthermore be expressed via the key-number: *GHG-reduction cost*. The *GHG-reduction cost* is calculated as the GHG reduction price necessary for the CAD project to become socio-economic break-even. For this analysis, of course, income elements from the GHG reduction achieved must not enter the calculation. On this basis the key number can be calculated as shown in Table 5.

Table 5 Break-even Green House Gas (GHG) reduction costs

	F	IRL	SP	GR	B	NL
Per day treatment capacity, tons/day	**120**	**144**	**460**	**93**	**200**	**600**
Euro / ton CO2 eqv.						
GHG reduction costs, €/ton CO_2eq	**26**	**79**	**27**	**-6**	**50**	**6**

As mentioned earlier the assumed market price of CO_2 emission allowances throughout the period 2006-2025 is 20 €/ton CO_2eq.

Socioeconomic conclusions

Two out of six cases are found to be highly socio-economic attractive when externalities are taken into account. Another three plants are close to break-even, and these could become attractive for society at large if existing non technical barriers were removed.
Lack of heat markets in some cases reduce the potential benefits related heat sales, energy substitution and CO_2-emission reduction. In general organic waste contributes considerable to the socio-economic benefits, and several cases could improve results considerable via additional input of waste. Furthermore it should be emphasized, that a number of externalities relevant for the socio-economic analyses have not been quantified, as indicated in Table 1, and most of these are expected to act in favour of CAD schemes.

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and 6 national reports.

The impact of national policies and economic frames for the development of biogas in Germany

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Introduction

At present, the use of biogas makes very intensive progress in Germany on the basis of the Renewable Energies Act (EEG). With an increase of the installed electrical capacity from 650 megawatt in 2005 to 1,100 megawatt, an all-time-high was achieved in 2006. Up to now, biogas is almost exclusively used for the generation of electricity and heat in cogeneration units at the sites of the biogas plants.

Latterly energy industry's interest in biogas is intense, however, they want to turn biogas into biomethane and feed it in available gas grids. In this way, biogas is the only regenerative alternative to fossil natural gas to contribute to the safe and sustainable supply of gas. Unlike other bio energy sources of the so-called second generation, biogas provides a highest level of efficiency in use and technical reliability already now. What role biogas will play in the medium and long term, depends on the political and economic framework conditions.

The Renewable Energy Act

The sustainable growth of the biogas sector in Germany was initiated by the Renewable Energy Law first passed in 2000. The Renewable Energy Law was and still is a success due to following four core elements:

1. priority connection of installations for the generation of electricity from renewable energies (wind-, biogas-, water- and solar cell-based electricity) to the general electricity supply grids,
2. the priority purchase and transmission of this electricity,
3. a consistent fee for this electricity paid by the grid operators, generally for a 20-year period, for commissioned installations,
4. nationwide equalisation of the electricity purchased and the corresponding fees paid.

The EEG ensures the increased use of environmentally friendly renewable energies, not through subsidies but through apportioning the costs. The grid operators and energy supply companies can pass on the difference in costs for electricity from renewable energies to the final consumer.

The biogas relevant minimum fees are paid for electricity produced in plants with a capacity of up to and including 20 megawatts using exclusively biomass. Paid per kWh the fees depend on the size of the installation and on the date of commissioning; the later an installation begins operation, the lower the tariff (annual degression). The tariff in the year of commissioning is paid for another 20 years.

The original law in 2000 calculated the minimum fee of biogas-electricity at Euro 0.10 /kWh for installations up to and including 500 kW installed electric capacity. This assumed that feedstock was free (e.g. liquid manure on a dairy farm or biomass waste).

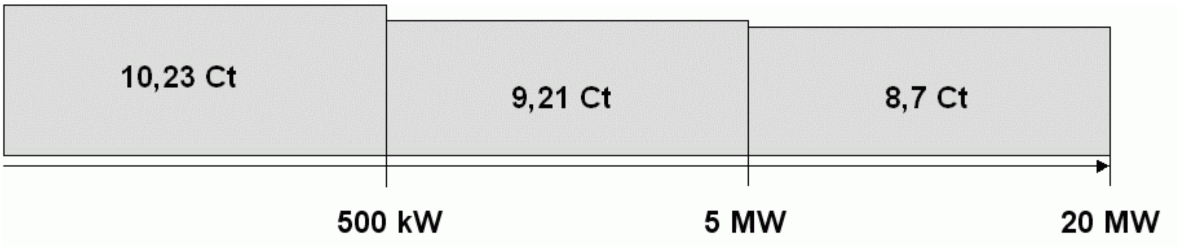

Figure 1. Fees paid for electricity in 2000 produced in plants with a capacity of up to and including 20 megawatts using exclusively biomass according to the Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act) 29.3.2000

But as recent studies assume, Germany has the technical potential to generate 72.2 bn. kilowatt-hours (kWh) or 260 Peta Joule (PJ) heat energy from biogas (BGW Biomassestudie 2006; FNR Biogasstudie 2006). The assumptions underlying these figures are conservative throughout. One third of this potential is based on energy crops (Figure 2). This essential part of Germany's potential for biogas production, could not be exceeded. The costs originated by production, harvest, transport and storage of energy cops were simply not covered by the fees.

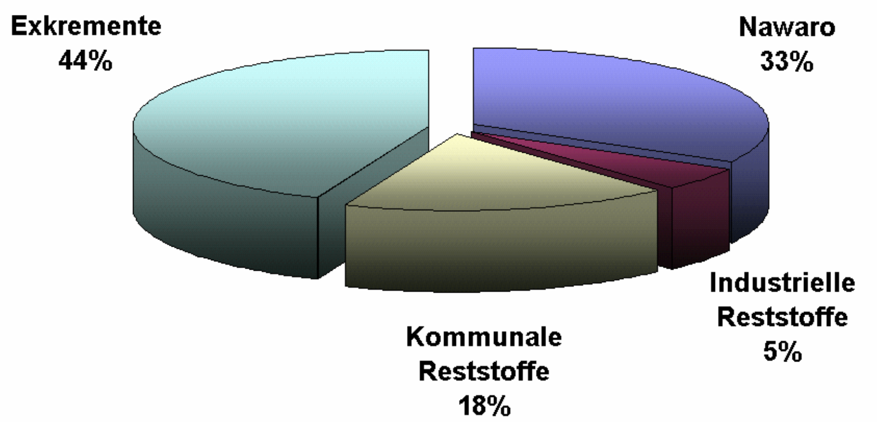

Figure 2. Distribution of biogas potential by class of substance (FNR Biogasstudie 2006),
(Manure = light blue, energy crops = dark blue, industrial residues = dark red, communal residues = grey)

This in mind the Renewable Energy Law in Germany was modified in 2004 with essential improvements for the biogas industry.

First of all another capacity step was integrated. So smaller installations up to 150 kWel get a higher minimum fee. But the most important modification was the foreseeing of the additional costs for growing energy crops. So the minimum fees increase by 6 cents resp. 4 cents per kWh if all electricity is produced exclusively

1. from plants or parts of plants which have originated from agricultural, silvicultural or horticultural operations or during landscaping activities and which have

not been treated or modified in any way other than for harvesting, conservation or use in the biomass plant,

2. from manure within the meaning of Regulation (EC) No 1774/2002
3. from vinasse
4. or a mixture of the substances listed above.

An overview of the price structure also considering another two bonuses - one for using combined heat and power generation, one for innovative technologies, each increasing the minimum fee by 2 Cent per kWh – gives Figure 3. All bonuses are cumulative.

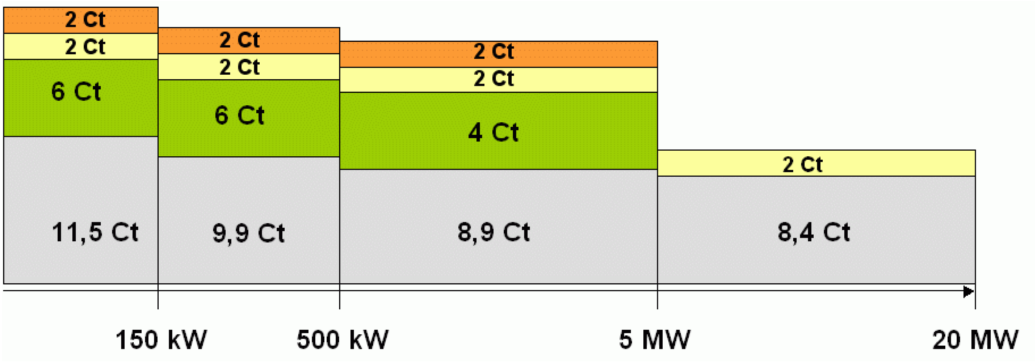

Figure 3. Fees paid for electricity in 2004 produced in plants with a capacity of up to and including 20 megawatts using exclusively biomass according to the Act revising the legislation on renewable energy sources in the electricity sector 21.7.2004

How important the implementation of the so called energy crop bonus for the advancement of biogas production in Germany was, shows the annual increase of biogas plants since 2004 in comparison to the years before (Figure 4).

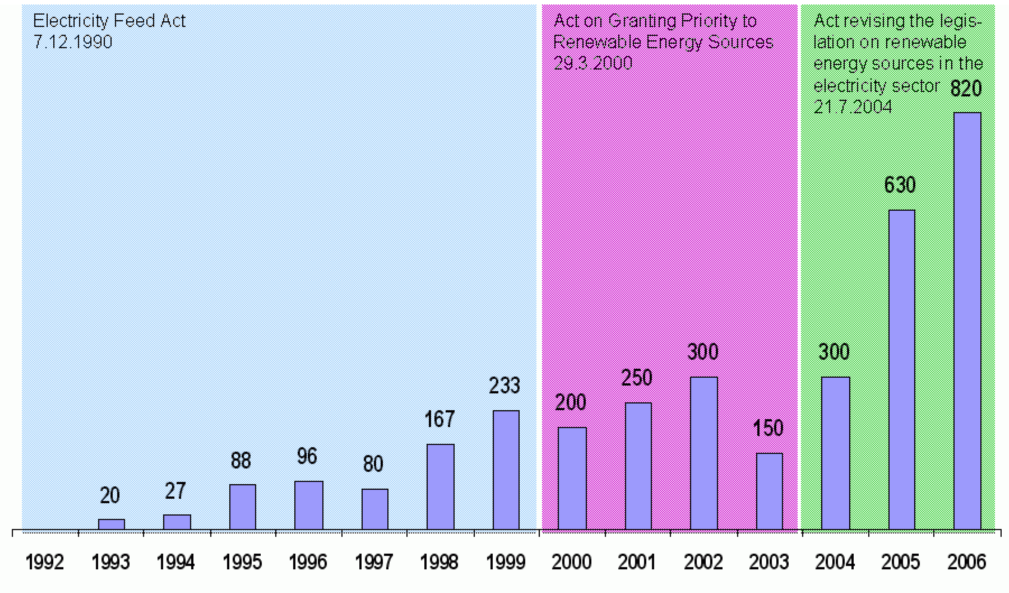

Figure 4. Annual increase of biogas plants in Germany subject to relevant legislation – Development 1992 - 2006

Still some obstacles

The obstacles for the continued positive development of biogas use can be grouped in four categories: 1. the political framework, 2. the legal framework, 3. the energy industry's framework, and 4. social acceptance:

1. Political framework
By adopting the Renewable Energy Act (EEG), the German parliament sent a very clear signal in favor of the further expansion of renewable primary products in Germany. The act and, in particular, the regulations concerning the obligation to provide access to the grid and the pegging of compensation rates for 20 years are very clear political signals. The adoption of the EEG amendment in August 2004, in particular, under which the biogas bonus was introduced, is the decisive stimulus for the further expansion of biogas use in Germany. Repeated fears in that past that substantial amendments might be made to the EEG have fueled uncertainty in the industry. The EEG act provides a solid basis for the production of electricity from biogas and that basis should be strengthened continuously until electricity from biogas can compete in the market. The positive effect of the EEG is seen, in particular, when looking at the problem of feeding of biogas in gas networks. There are no clear provisions for the connection to the network, conveyance of the gas or compensation. Despite the intense interest in feeding biogas in gas networks by several parties, the projects are implemented only very reluctantly. It can also be seen that biogas feeding is unproblematic only where network operators or energy suppliers are party to the projects. The target of planning and implementing projects primarily under aspects of site factors has clearly not been obtained in the area of gas feeding.
Here, questions of the political course in relation to land use should be considered. On the background of the necessary optimization of land use, politics should set a sign of what optimized land use could look like. The present discussion of the future use of BTL (biomass to liquid) fuel of which nobody knows when and at what price it will be available and which is fueled by the German automotive industry time in the first line, creates uncertainty among political decision makers and is an example of a non-optimal course. At present, no decision as to what fuel will power our cars in ten or 15 years can be made. If there is an option which with high area efficiency and good ecobalance is available today, the question should be asked why we should wait for a vague option to take shape?

2. Legal framework
The legal framework will take a summary look at questions of the approval procedure. As biogas use is connected with a number of legal areas; the potential plant operator must take many legal hurdles. Examples to mention include the approval under building and emission prevention laws, waste and fertilizer laws as well as requirements under water legislation. As the number of biogas plants is rising, safety considerations are becoming important. Anyone with a daily exposure to these issues feels that new requirements and problems relating to approval law crops up almost every week. This development can be explained with reference to the increasing complexity of biogas technology even if it is difficult to understand for someone wanting to build a biogas plant. In some German states, the problems in relation with approvals are resolved on the basis of so called „biogas manuals“ which are helpful to the potential biogas operator and also the approval authority to find their way through the jungle of requirements and encour-

age the adoption of a uniform approach. An original and important task of Fachverband Biogas e.V. is, by its work, to contribute to the definition of the legal framework in a way that biogas projects can be implemented under reasonable conditions.

3. Energy industry framework
In addition to the political framework, legislators need to define the energy industry's course and the activities of the approval authorities must be geared to the changing general conditions. Under the present global economic conditions, the generally accepted triangle of energy supply - supply security, economy and environmental compatibility - can only work if the energy industry structures are actively developed towards the decentralization of the energy supply. Regenerative energy production from biogas is always local. As regards electricity production, the EEG has set a framework which fits this decentralized structure. There is no such framework for gas feeding. The provisions in the Energy Industry Act (EnWG) regulating the feeding of biomethane are absolutely insufficient as regards network connection, conveyance and accounting. Projects for the feeding of biogas are implemented only if the network operator is willing to cooperate with the party feeding the gas. Investors from outside the energy industry cannot be sure of their investment. This situation is absolutely discontenting and counterproductive because good projects can generally be prevented by private industry interests.

4. Social acceptance
Generally, biogas is still perceived as a positive affair. The fact that the situation is changing can be seen by the growing number of instances where resistance to concrete biogas projects is mounted. Most reservations come from the unsubstantiated fear of gas and apprehensions of intense traffic, bad smell or noise. Plus there is the apprehension concerning the growing of energy crops which are regarded as intensive crops predominantly by environmental protection societies and made the scapegoat for environmental damage. The intensive discussion in 2007 of the amendment of the EEG act will essentially focus on the extent to which restrictions for the growing of energy crops can be included in the amended EEG. Initial position papers have been published by ecology societies (demands by DVL, NABU 2006) and call for a limitation of the area planted to corn to maximum 50%, proof of provision of ecological compensatory areas and the abandonment of fungicides and insecticides. Notwithstanding the result of this discussion in connection with the EED amendment, the question of social acceptance will not only be critical to the implementation of biogas projects, it will also have a strong influence on political decision-makers.

Required framework

To ensure that the potentials for biogas use can be exploited in the medium term, the framework for bioenergy use should be defined. The core requirements for the political and social framework derive from the obstacles discussed above:

1. Clear political statements concerning the further expansion of biogas as a key technology for the secure, economic and ecologically compatible supply of energy. The accepted advantages of biogas in relation with area efficiency, availability of technology, ecological compatibility and regional valued-added should be the basis for political decisions on the encouragement of biogas use. The central message should be: „Until the foreseeable time when renewable energy from biogas is viable in the market, the framework conditions will be such that investment is safe.“

2. The conditions for the integration and compensation of biogas in available networks should be clear and transparent on the example of the EEG. The core points are a clear definition of the conditions for connection and feeding, the costs of conveyance and storage and of regulations for the payment of compensation for supplied biomethane. The possibilities of the local feeding of energy provided under the EEF act must also be initiated by the clear definition of interfaces.

3. The biogas industry on its part must improve the framework for the safety and quality of the construction and operation of biogas plants. The relevant provisions by the professional organizations and quality assurance systems should be such that accidents and technical shortcomings are avoided. Plant operators should have the possibility of acquiring technical qualification to ensure the safe and efficient operation of plant and equipment.

This is where we will be

Biogas technology is a way of obtaining a universal energy source from biomass. The conversion process is efficient and state-of-the-art. Assuming that, in the medium term, framework conditions can be established which allow the biogas industry the optimal use of an area of 2.2bn ha, about 17% of the German electricity demand could be supplied by the year 2020. Calculated on the basis of the EEG compensation rates, an installed electrical capacity of the order of 9,500 megawatt could earn 11bn Euro from electricity production. Of these earnings, a substantial share would go to the farming sector. Given an export share of 30%, plant sales would account for totally 7.6bn. Euro.

Alternatively, in view of the expected liberalization of access to the available gas network, biogas could supply 20% of the German gas demand or 35% of the traffic volume. If all EU member states and the accession candidates were included in a strategy of sustainable gas supply, biogas could make an important contribution to securing the long-term gas supply in the EU.

In the opinion of Fachverband Biogas e.V., the biogas sector will account for an important part of the energy supply in Germany and the EU by the year 2020. German companies will be the technology leaders in the provision of energy from biogas. The successful implementation of systems for the local provision and supply of energy will be a key competence for which there is a need especially in developing and threshold countries.

So the success of making biogas a firm constituent part of the agricultural production systems is of critical importance to the industry. In Germany, biogas projects of all sizes (50 – 5000 kilowatt installed electrical output), whether based on renewable primary products or waste-fired, must be implemented to ensure the local supply of electricity and gas feeding, and under most different operator constellations. Only if we succeed in adapting the projects to the widely varying site conditions and provide relevant optimized solutions, can biogas technology unfold its full potential.

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Efficiency of energy crop digestion - Evaluation of 41 full scale plants in Austria

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Abstract

This paper reports on an ongoing investigation, aiming at the definition and measurement of energetic, business economic, ecological, and socio-economic parameters, characterising the overall production chain of biogas systems and their performance. The production chains studied range from the cultivation and supply of energy crops (including on-site transport and storage), to bioconversion (pre-treatment, digestion), on to final biogas utilisation and use of the digestate. In total about 250 parameters were identified, allowing for an accurate, multi-dimensional description and evaluation of biogas recovery from energy crops. Parameters included allow for a detailed functional description, and comprise measurable performance parameters as well as derived (calculated) efficiency parameters. Based on the pre-defined list of parameters, detailed data have been collected over the last two years from a set of 40 full-scale and operational Austrian biogas plants. The collected data have been used to examine the productivity of the plants by means of data envelopment analysis (DEA). The performance of each plant, measured by multiple inputs and outputs, is compared with the most productive plants in the sample (best practice benchmarking). First results from the benchmarking analysis show considerable differences in production efficiency, depending on the choice of substrate, plant size, and operational conditions.

Keywords

Anaerobic digestion, biogas from energy crops, efficiency criteria, best practice benchmarking, data envelopment analysis, DEA

Introduction

Driven by the need to achieve ambitious political goals, such as the one under the Kyoto Protocol (-13% greenhouse gas emissions by 2008/12, relative to 1990 levels) or the Green Electricity Act 2002 (renewable electricity share of 78.1% by 2008), an effective promotion of renewable energy technologies has been pursued in Austria in recent years. In particular, feed-in tariffs between 10.3-16.5 EUR Ct / kWh_{el} for ‘biogas’ electricity fed into the grid have led to a remarkable boom in the construction of agricultural biogas plants (Markard et al., 2005). As a consequence, the number of plants rose from 110 at the end of 2003 to more than 200 by the end of year 2004 and to 350 by 2006 (as a comparison: in Germany over 3,500 biogas plants were in operation at the same time). Both in Austria and Germany, the majority of the plants use mainly energy crops (silage) for digestion. However, up to now the promotion of energy crop digestion was hardly linked to efficiency criteria. As a result many different technologies and specific applications occurred on the market, some of which were not very energy-efficient and reliable.

Due to the attractive feed-in tariffs granted in Austria that are guaranteed for a duration of 13 years (BGBl, 2002) and 10 years from 2006 onwards, anaerobic digestion of energy crops currently mainly aims at the generation of electricity. As a consequence, regrettably, the heat energy produced in co-generation units remains largely unused. Even worse, many plants use electricity for cooling purposes, in order to prevent adverse effects from self-heating of crop digesters. By this means, in many cases up to two thirds of the available technical energy potential remains unused.

Generally speaking, the production chain of biogas systems is fairly complex. Every process step is associated with a potential loss of energy. A reduction of these energy losses can contribute to a better economic and ecological performance of energy crop digestion, enhancing overall efficiency. Optimisation potentials can be found at nearly every stage of the production process – starting from the cultivation and the supply of energy crops, via bioconversion (digestion), on to final gas utilisation and use of the digestate.

In 2004, IFA-Tulln initiated a monitoring- and benchmarking project that includes a detailed investigation of over 41 Austrian energy crop digestion plants. The project also aims at creating and establishing an evaluation system for the objective and transparent assessment and benchmarking of the productivity of biogas plants by means of energetic, business economic, ecological and socio-economic criteria, characterising the overall production chain of biogas. Since anaerobic digestion has the potential of reducing greenhouse gas emissions (Braschkat et al., 2003), an important objective of the project is to evaluate the environmental impacts through the overall “crops to energy” process. Finally, positive and negative socio-economic impacts have been accounted for to a limited extent by means of a questionnaire survey undertaken among plant operators (subjective valuation, supplemented by measurable data).

Material and Methods

Selection of biogas plants and data acquisition

Data acquisition was performed on site by means of personal interviews of plant operators. Representative samples were taken from the substrate, digester, fermentation residues, and the biogas. Representative cooling, safe transport and appropriate storage was scrutinised as well. Samples were analysed according to German Standard Methods (Anon., 2000). The biogas plants investigated were carefully selected and cover the entire spectrum of existing plant types and operations in Austria. The installations considered are geographically distributed over all nine of the Austrian provinces, ranging from small-scale installations in alpine agricultural regions in Western Austria to the larger scale operations and farm areas in Eastern Austria. Large plants up to 1,672 kW_{el} of electrical capacity were investigated as well as very small installations down to 18 kW_{el}. It was also tried to achieve a representative spectrum of the substrates applied. Both single substrate (energy crops) installations, as well as co-digestion plants (agricultural by-products, industrial bio-wastes) have been analysed.

Identification and definition of specific evaluation parameters

In order to describe a biogas plant comprehensively, it is necessary to collect specific data on the process technology as well as on the overall mass flow, and on business economic, environmental and socio-economic aspects. Parameters identified cover the areas (1) substrate provision, storage, pretreatment; (2) biogas production (digestion); (3) gas utilisation; and (4) digestate handling and disposal. For the individual thematic areas interfaces were defined, which allow for a clear allocation of the parameters to the thematic areas.

Parameter selection was discussed in a specialist group, mainly based on German experience gained in the monitoring of biogas plants (Weiland, 2004). More than 250 specific variables could be derived, describing the overall biogas recovery process in full detail. The parameters identified can be divided into 3 groups: (1) general functional description, (2) measurable process conditions, (3) calculable variables (Table 1). The headlines listed in Table 1 under the topics ‘substrate’, ‘digester’, ‘digestate’, and ‘biogas’, in each case include numerous subheadings. Altogether more than 250 parameters were applied for a comprehensive description of the plants investigated.

Efficiency measurement of biogas plants by means of Data Envelopment Analysis

For the overall performance assessment of the biogas plants, Data Envelopment Analysis (DEA) was used (Farrell, 1957; Charnes et al., 1978, 1994; Seiford and Thrall, 1990; Cooper et al., 2000). DEA is a widely applied non-parametric linear programming method for comparative efficiency measurement. It allows the determination of an “efficiency frontier” of production processes. In contrast to alternative parametric econometric approaches, such as stochastic frontier analysis, DEA does not assume any specific functional form, thus avoiding problems of model misspecification. Moreover, it allows for the inclusion of non-economic (e.g. environmental impact, socio-economic) variables in the assessment, as well as the use of multiple inputs and outputs.

Apart from the identification of inefficiencies in production, DEA also enables to determine the scope for improvement of inefficient plants and/or to formulate precise goals for efficiency improvements. In this respect the method is also useful as a planning tool in technology management. It further allows for the consideration of both technical and economic efficiency (the former deals only with technological characteristics of production, while the latter also takes economic variables – such as cost and prices – into account). Finally, the analysis can be further extended to also take into account environmental and social impacts of technology use. Note that these may be positive or negative, and thus have to be appropriately taken into account with respect to their impact on the ranking of a specific plant (or ‘decision making unit’). The current analysis aimed at defining and establishing characteristic and to a large extent objectively measurable input and output parameters that are able to comprehensively describe the biogas plants studied. By this means a comparative evaluation of the production efficiency of the biogas plants can be achieved. The detailed

Table 1. Grouping of parameters applied for evaluation of the biogas plants investigated

General functional description	Measurable process conditions	Calculable variables
SUBSTRATE		
Quality / quantity Transport Storage Pretreatment Costs	COD[1] TKN[2], NH_4-N TS[3], VSS[4]	t / year Costs/year
DIGESTER		
Startup Investment costs Subsidies Annual costs Process steps Substrate dosage Digester type Digester equipment Digester mixing	T, Self heating pH, VFA[5], COD, TS, VSS TKN, NH_4-N Process energy demand Sludge recirculation	Residence time Hydraulic loading VSS degradation Biogas yield
DIGESTATE		
Storage type / cover Treatment / Dewatering Use	pH, COD, TS, VSS VFA, TKN, NH_4-N CH_4-formation Hygienic status	t / year
BIOGAS		
Gas holder Upgrading Quantity /utilisation	CH_4, H_2S	Calorific value Electrical efficiency
PERSONNEL EXPENDITURE		
SALES REVENUES / OVERALL ECONOMICS		
ECOLOGICAL- / SOCIO-ECONOMIC PERFORMANCE		

[1] Chemical Oxygen Demand; [2] Total Kjeldahl Nitrogen; [3] Total Solids; [4] Volatile Suspended Solids; [5] Volatile Fatty Acids

Table 2. Performance figures of the technical monitoring and benchmarking

Parameter	Unit	Median[1]	min.	max.
Amount of processed substrate	$t_{Substrate}/d$	12.5	0.8	54.8
Hydraulic retention time	$m^3_{RV}/(t_{Substrate}/d)$	139	49	483
Organic load (dry substance)	$kg_{VSS}/(m^3_{RV} \cdot d)$	3.39	1.19	8.83
COD load	$kg_{COD}/(m^3_{RV} \cdot d)$	5.09	2.03	13.29
Amount of VSS	t_{VSS}/d	2.33	0.32	13.88
Biogas generation	Nm^3_{biogas}/d	1,461	232	8,876
Biogas productivity	$Nm^3_{biogas}/(m^3_{RV} \cdot d)$	0.89	0.24	2.30
Carbon degradation	%	81.34	67.15	97.09
Average biogas yield	Nm^3_{biogas}/kg_{VSS}	0.673	0.423	1.018
Methane content in biogas	%	53.01	49.01	67.01
Use of heat (process heat and end use)	% (rel. to total output)	28.9	0.0	87.6
Electrical efficiency	%	31.8	18.3	38.3
Degree of heat utilisation (end use)	% (rel. to total output)	14.7	0.0	43.3
Degree of utilisation of the energy contained in biogas (H_u)	%	46.9	27.5	80.2

RV: Reactor volume; H_u: Net calorific value; VSS: Organic dry substance

[1] Instead of average values the median was calculated

Information on the overall production chain and on practical experience with biogas plants was fed into a database and used as an input for the DEA. For the exemplary analysis reported here, the parameters (1) personnel expenditure, (2) yearly amount of processed substrate and (3-5) annual yield of biogas, power and heat, respectively, were used

Results and Discussion

Collection of performance data from biogas plants

The consolidated results from data acquisition and analysis are given in Table 2. Although just representing a minimum number of selected parameters, the broad range of results obtained can be clearly recognised. The amount of substrate processed varied beetween less than 1 t/d in the smallest installations up to 55 t/d in large plants. The biogas productivity ranged from 0.24 to 2.3 $m^3 m^{-3} d^{-1}$. Correspondingly, the biogas yield varied between 0.42 and 1 $m^3 kg^{-1}$ VSS. A similarly broad range of corresponding results was found in the evaluation of the business economic parameters. The electrical efficiency was as low as 18% in the worst case, while over 38% was achieved in well operating installations. The degree of heat utilisation of about 15% (median) was generally low. Best performing plants could use more than 40% of heat, while many of the installations did not make any use of the waste heat from power generation. Forteen installations produce 100 kW, 11 produce 500 kW and 8 produce 250 kW elctrical power. Five were very small installations (50 kW_{el}) and three were bigger than 1 MW.

About 71 % of 59,000 t dry organic substance, used annually in the 41 plants considered, origine from energy crops, 12 % from manure and 17 % from other biogenic by-products and wastes. With a share of 53 %, maize dominates the crops used in digesters. Togehther with corn cob mixture (22 %) and maize corn (2 %) the overall share of maize amounts 77 %, followed by grass (9.4 %), grain (5.5 %) and several other crops (sun flower, wheat, clover). Concerning manure, pigs dominate (45.6 %), followed by cattle- (36.6 %), chicken- (7.9 %), horse- (6.3 %) and turkey manure (3.6 %). Food leftovers (20 %) dominate the co-substrates used, followed by flour mill by-products (14.4 %), oil processing- (11.3 %), sugar beet-(10.8 %), potato- (7.4 %) and various other wastes of minor quantity.

The majority of 99 plants considered runs 2-step digesters (85 %), 12 % use 3-step-, the remaining more than 3 digester steps. About 29 % of the plants run at 42^0C, 27 % at 40^0C and 22 % at 38^0C. Just 10 % operate at 48^0C and 12 % at 55^0C. The most common residence time is 100 days (32%), followed by 150 days (24 %), 200 days (15 %). Anyhow, 10 % of the installations use 250 days and 15 % even more than 250 days. Just 5 % use less than 50 days residence time. The resulting organic loading amounts 4 kg VSS m^{-3} d^{-1} (32 %), 5 kg in 22 % and 3 kg in 20 % of the 41 plants considered. Seventeen plants use loadings between 6-8 kg, and 10 use loadings below 2 kg VSS m^{-3} d^{-1}.

Efficiency measurement of biogas plants

An important part of the research project was related to measuring the relative production efficiency of the biogas plants studied. ‘Relative’ in this context means that performance is measured relative to the plants with the best performance contained in the data sample. DEA allows to find the (hypothetical) frontier curve of production efficiency, determined by the most efficient plants or ‘decision making units’ (DMUs) contained in the sample.

In the following, an exemplary efficiency ranking output produced with the DEA software ‘DEA-Solver’ is shown (Cooper et al., 2000). Figure 1 depicts the result of a data envelopment analysis undertaken with a CCR-O[2] model specification for two inputs (ODS, time spent on plant operation) and two outputs (net electr. prod, total heat prod.) as an illustration. As can be seen, for a model that assumes constant returns to scale (CRS; i.e. when all inputs are increased by a given percentage output increases by the same percentage), plants

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[2] Named after Charnes, Cooper and Rhodes (1978), output-oriented model specification (i.e. a model that aims at maximising output(s) for the observed amount of any input(s), in contrast to input-oriented models that aim at minimising inputs for producing at least the given output levels).

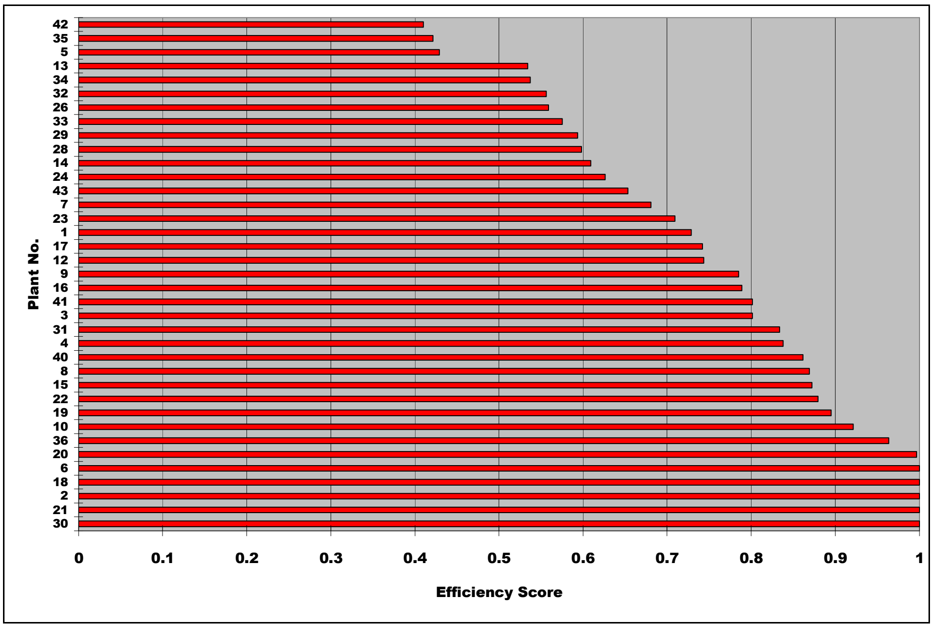

Figure 1. Data Envelopment Analysis with a CCR-O[1] model specification (sample of 37 plants; inputs used: amount of organic dry substance, time effort; outputs used: net electricity production and total heat production)

2, 6, 18, 21 and 30 determine the efficiency frontier (efficiency value of unity), while plants 42, 35, and 5 show the worst performance of all 43 plants considered.

Further work is currently under way in which a whole battery of DEA model specifications is used against a comprehensive data set of 41 plants. The efficiency benchmarking also takes into account cost, value limitations, and the impact of certain environmental and social sustainability indicators on the efficiency score (ranking).

Conclusions

An improved energetic, business economic, environmental, and socio-economic performance of biogas plants can lead to a higher degree of acceptance of the biogas technology as a meaningful and sustainable future alternative heat and power production system.

Based on the above-mentioned investigations, an extensive database was generated, which forms the foundations for the development of a transparent evaluation system for biogas plants that uses DEA as a pillar for best practice assessments. The evaluation system represents a management tool for comparing and balancing of assessment criteria, studying sensitivities to parameter variation, and defining efficiency criteria and targets for the future biogas market.

With the help of DEA, adapted to the specific needs of biogas system assessments (Madlener, 2005), productivity information is fed into a user-friendly best-practice evaluation system suitable for practical use. Based on this evaluation system, both existing and planned biogas plants can be assessed in a systematic way, and appropriate measures for further improvements of individual production stages as well as system optimisations derived. Experiences from best practice biogas plants can avoid poor technological development and technology implementation, a common phenomenon observed during the early market introduction phase of new technologies.

Acknowledgement

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Biogas upgrading and utilization as vehicle fuel

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Biogas can be used as fuel in vehicles specially adapted to methane gas. Before using biogas as vehicles fuel cleaning and upgrading of the gas is needed meaning separation of primarily hydrogen sulphide, water and carbon dioxide. Biogas has been used as vehicle fuel in large scale systems for buses and other vehicles since 1996 in Sweden. Today there are over 30 upgrading plants in operation or in construction phase in the country and during 2006 54 % of the gas delivered to vehicles was biogas. Biogas as vehicle fuel is given more and more interest world wide and last year both Germany and Austria set up national targets of 20 % biogas in the gas sold to vehicles.

Biogas as vehicle fuel in Sweden

Biogas is a renewable fuel that can be used in the transport sector and thereby replace fossil fuels like petrol and diesel. Sweden is in the forefront in this area and the first pilot plants for biogas upgrading to vehicle fuel was built already in the early 90´s. In 1996 biogas started to be used in large scale systems, for buses and other vehicles, in for instance in the town of Trollhättan [1]. Today there are over 30 upgrading plants in operation or in construction phase in the country. In the end of 2006, 11 500 vehicles used gas as fuel in the country, 10 400 light duty vehicles, 760 buses and 340 lorries. Biogas stood for as much as 54 % of the total sales of gas to vehicles, the rest being natural gas, Figure 1. The sales of biogas to vehicles are increasing every year. The increase of sales 2006 compared to 2005 was as much as 48 %. Increased sales of biogas and natural gas for vehicles represent an increase of vehicles and filling stations each year, Figure 2. Number of public and private filling stations amounted to 95 by the end of 2006 in Sweden [2].

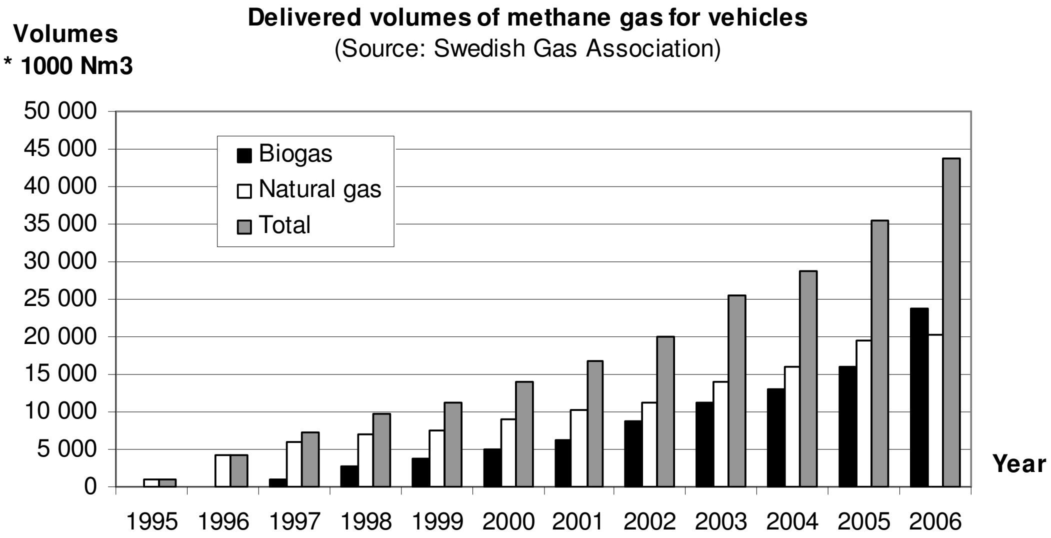

Figure 1. Sales of methane gas to vehicles in Sweden [2]

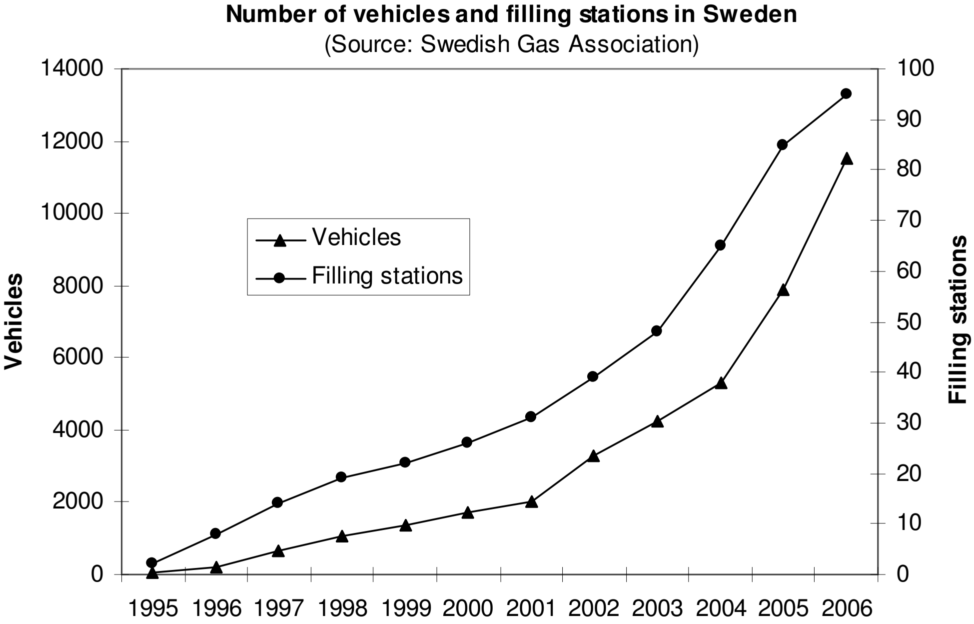

Figure 2. Vehicles and filling stations for methane gas in Sweden [2]

Biogas cleaning and upgrading

In order to use biogas as vehicle fuel the gas needs to be cleaned and upgraded to vehicle fuel quality. This process is needed to avoid corrosion and mechanical wear and to meet quality requirements of gas applications. Cleaning foremost imply separation of particles, water and hydrogen sulphide. Upgrading means removal of carbon dioxide to raise the calorific value of the gas, which increases the driving distance for a specific volume of gas. Cleaning and upgrading is done to get a standardised gas quality. In 1999 a standard for biogas as vehicle fuel was established in Sweden, the main requirements in this standard is listed in Table 1.

Table 1. Extract from Swedish standard for biogas as vehicle fuel, SS 15 54 38 [3]

Parameter	**Demand**
Lower Wobbe-index, MJ/m_n^3	43,9 – 47,3
Methane content, vol-%	97 ± 2
Amount of water, mg/m_n^3	< 32
Dew point, °C	5 °C below water pressure dew point at maximum storage pressure during lowest monthly mean day temperature for current location
$CO_2 + O_2 + N_2$, vol-%	< 5
O_2, vol-%	< 1
Total sulphide, mg/m_n^3	< 23 (equivalent to approx. 16 ppm_v H_2S)
Nitrogen compounds, mg/m_n^3	< 20 (excl. N_2) accounted as NH_3
Particles	< 1 μm

Biogas consists of about 30-40% carbon dioxide, which means this is the most equipment demanding, and thereby also the most costly component to separate from the gas. How carbon dioxide is separated also effect how biogas is cleaned from water and hydrogen sulphide. For instance hydrogen sulphide can be separated already in the digestion chamber, before carbon dioxide removal, in the carbon dioxide removal process, or separated in the upgraded gas. Since hydrogen sulphide is a highly corrosive component together with water it is usually good to separate it as early possible in the process.

There are several commercial methods available for separation of carbon dioxide from biogas. The most common method used in Sweden is absorption of carbon dioxide in water at elevated pressure. The method is called water scrubbing and can be out-lined with or without regeneration of the water. The second most common method in Sweden is an adsorption process called, PSA, Pressure Swing Adsorption. Carbon dioxide is adsorbed on activated carbon at elevated pressure and released when the pressure is reduced down to vacuum. Absorption processes can also be outlined with organic solvents and at one plant in Sweden polyethylene glycol, with the trade name Selexol® or Genosorb® has been used. Another organic solvent that is used is COOAB, a proprietary amine scrubbing process, which can absorb carbon dioxide at low pressure and is regenerated with heat. Biogas plants in operation or construction phase in Sweden are shown by Table 2.

Table 2. Upgrading plants in Sweden, operation or construction phase, 2007

Upgrading method	**Number of plants**
Absorption, water scrubber, regeneration	15
Absorption, water scrubber, no regeneration	6
Adsorption, PSA	7
Absorption, COOAB	2
Absorption, Selexol®	1

The total cost for upgrading biogas is approx. 0.1-0.2 SEK per kWh cleaned gas. According to a evaluation of some Swedish plants the electricity need for upgrading biogas in a water scrubber or a PSA corresponds to about 3-6 % of the energy content in the upgraded gas. [4]

All upgrading methods imply some loss of methane in the process. Since methane is a strong green house gas (GHG) with about 20 times stronger GHG affect than carbon dioxide it is important to keep the methane losses low. There are also other strong reasons to why emissions from upgrading plants should be kept low like safety, economy and smell. For water scrubber and PSA suppliers have historically guaranteed 2 % maximum methane losses in upgrading plants in Sweden. For the COOAB process the supplier claim less than 0.1 % methane losses since this is a more selective process. The Swedish Waste Management has now started a voluntary agreement to get a more structured way of following up on emissions from upgrading plants. So far almost all of the co-digestion plants in Sweden has joined the system which means a thorough investigation of the plant every third year.

Incentives and barriers for biogas as vehicle fuel

In the early 1990s the use of biogas as vehicle fuel in Sweden was initiated by municipalities or companies owned by municipalities. Biogas at sewage treatment plants was seen as a resource since it's a locally produced renewable fuel. Municipalities still play an important roll for biogas as vehicle fuel since the majority of gas in Sweden comes from sewage treatment plants or municipal waste handling companies and they often take the investment decision of an upgrading plant. Private companies have now also stepped into the arena. This is foremost in the area of selling vehicle fuel and building filling stations. But energy companies like E.ON Gas and Gothenburg Energy have also invested in upgrading plants and are actively working for more renewable gas.

Use of biogas and other renewable fuels in the transport sector have and have had strong government support in Sweden. One reason for this is that the transport sector is the sector which utilizes most oil in Sweden, the majority of the electricity production in the country comes from nuclear power and hydro electric power. Example of government support are investment programs with up to 30 % investment support, zero tax on biofuels (only valuation tax), reduced income tax for company car users, no congestion fees in Stockholm etc.

When it comes to using new fuels there is a “hen and egg” situation. Meaning it is difficult to sell vehicles when there are few filling stations and difficult to get good economy for filling stations when there are few vehicles. Here gas companies have played an important roll in Sweden in building fillings stations and promoting the fuel. They see vehicles as an alternative market for their product. Biogas and natural gas cost about 20-30 % less than petrol in Sweden. This is an important argument for private costumers. The knowledge of biogas among consumers is still rather low and a lot of information is needed through different channels. Some areas that specially can concern new costumers are availability of filling stations, vehicle functionality and long term overall economy.

In building new biogas markets municipalities again have had a great roll in Sweden since they can affect public transport and make local regulations to promote low emission gas buses in sensitive town areas. When building an upgrading plant it is important to get a good base load and buses or for instance garbage trucks are excellent for this. If biogas can be injected into the gas grid (originally built to transport natural gas) this also means that all of the gas from the biogas plant can be used. The gas grid also works as a back-up and biogas can reach new costumers. In Sweden there is only natural gas in the western part of the country and so far four biogas plants inject biogas into the grid.

Biogas as vehicle fuel in Europe

There is a great potential to increase the production and use of biogas in Europe. Biogas can after cleaning and upgrading be used in all applications that use natural gas. Renewable gas can also be produced from gasification of wood a subject which has reached great interest the latest years. In Sweden, Gothenburg Energy is planning a 100 MW gasification and methanisation plant. The plan is that the plant will be in operation 2012 and inject the renewable methane gas into the gas grid. [5]

In January 2007 the Institute for Energy and Environment in Leipzig, Germany, presented a study, where the potential to produce renewable methane from biogas production and gasification of wood was evaluated. The conclusion was that the potential to produce renewable gas in the 28 members (or coming members) in EU, plus Ukraine, Belarus and the European part of Russia amount to us much as 500 milliard normal cubic meter of methane gas 2020. This can be compared to the use of natural gas in EU 28 in 2005 which amounted to about this much [6].

Belief in biogas as vehicle fuel was shown in the summer of 2006 when both Germany and Austria set up national targets for biogas as vehicle fuel. The German target set up by the German Gas Association was 10 % biogas in natural gas used in the transport sector 2010 and 20 % 2020. The target is based on long term tax exemption on biogas and reduced tax on natural gas. In Austria the a target was set on 20 % biogas in natural gas in the transport sector, also based on tax reduction on natural gas [7].

Conclusions

Biogas can be used as vehicle fuel, this has been shown in Sweden since the beginning of the 90´s, already in 1996 biogas was started to be used in large scale systems for buss fleets. Biogas upgrading is a commercial and mature technology, but it still has potential to be further developed. Incentives are needed to get a development of biogas as vehicle fuel, such as tax exemption. In Sweden municipalities has played an important roll in the development supported by government grants. There is a great potential to increase the production and use of biogas in Europe and the natural gas grid can be used for efficient distribution of the gas. Increased production and use of biogas will improve the security of supply as well as create local job opportunities.

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AD on the move – United Kingdom 2007

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Introduction

In the United Kingdom anaerobic digestion (AD) has a long established role in the wastewater treatment such that (with the exploitation of landfill gas) the UK is the leading biogas producer in the Europe. In contrast it has lagged far behind Denmark, Sweden, Germany, Austria and Switzerland in the application of AD in other agriculture, the food processing industries and in the handling of municipal solid waste (MSW). However, during the last three years there has been a sudden surge of interest in the potential of AD manifested by the number of new plants and a change in government policy. This paper therefore will attempt to elucidate the factors underlying the changes and their implications for its future development.

At the outset, however, it is important to note that the biological degradation volatile organic matter in the absence of air in the controlled conditions of a digester producers three **new** products (bio-methane, carbon dioxide and a quality assurable bio-fertiliser) all of which are marketable. This combination is fundamental to the case for AD. The raw materials include animal manure, crop residues or purpose grown energy crops, the hitherto 'wastes' from the agri-processing industries and the residues from food manufacture, retailing and consumption. The system is flexible in the range of raw materials that can be processed and at the scale at which it can be operated. There is however a caveat to be introduced at an early stage. Its flexibility in the range of suitable feedstocks and product uses draws it into the administrative framework of at least three government departments – Trade and Industry (DTI), Environment, Food and Rural Affairs (DEFRA) and Transport (DfT) where the regulations of one can impede the activities of a whole.

If the contention that AD is now on the move in the UK is to be sustained, the first step must be to consider the significance of a recent answer by David Miliband MP, Secretary of State for the Environment in response to a question made to Parliament:
"The Government is committed to making the most of anaerobic digestion to contribute to a number of key objectives, notably reducing greenhouse gas emissions from waste management and agriculture and improving air quality and water quality as well as a source of renewable energy."
In fact the Minister has recognised publicly the multi-purpose functions that AD has to offer. The question now arises as to why this and similar recent ministerial pronouncements are so significant. The current situation needs to be set into the context of previous development and the challenges/ obstacles with which AD has had to contend.

Background to the present situation

Table 1 below shows in so far as it is possible from the available evidence the course of AD development since 1975. The total volume (m^3) of digester capacity constructed in each year provided a common denominator for assessing progress while a cluster analysis has been used to identify any break points.

Table 1 Indicative progress in the scale of AD adoption in the UK

Construction year	**Number installed**	**Digester total volume (m^3)**	**Observations**
1975	2	800	
1978 – 82	15	1,297	Inc. 4 installations of $70m^3$ & a $2m^3$ tank
1983 – 88	8	2,616	Inc. 3 installations of $70m^3$
1989 – 92	17	3,515	-
1993 – 98	11	1,805	Inc. 2 of unknown size
2002	2	8,003	Holsworthy Biogas Plant (2002)
2003 – 06	15	21,690	Inc. on farm slurry only, on farm co-digestion with industrial waste & dedicated source separated MSW plants
2007	4 (under planning)	19,688	Inc. energy crops, food waste & co-digestion manure and industrial waste& MSW

Sources: Baldwin, D. (1993) [1] and supplemented by information from the biogas companies and owners

In the first 20 years development was farm based and the biogas used in situ as hot water for the farm buildings, domestic heating, cooking and to a lesser extent electricity. During this period there were two phases with a breakpoint about 1988 and each distinguished by different drivers – the first by energy costs and the second by pollution abatement. In the first stage up to 1982 the main stimulus was the escalating price of oil during the political instabilities of the Middle East. However, technical problems, maintenance costs and falling energy prices contributed to a number of plants falling into disuse [1].

Between 1989 –98 escalating numbers of complaints, over 9,000 a year in 1995/96, about odours from slurry spreading [2] gave rise the a second phase of AD installation when a 50% grant was available from the Farm Waste Management Scheme and could be used towards the cost of installing a digester. At the time there was also growing concern over emissions of methane, nitrous oxide and ammonia from livestock. The then Ministry of Agriculture, Fisheries and Food (MAFF) now DEFRA, noted role of AD and commissioned a series of investigations to establish the scale of the emissions. It was, in fact, at this time that protests about the odours from spreading pig, chicken and cattle manure in the popular tourist areas of North Cornwall were driving force for the Holsworthy Biogas Plant then known as the North Tamar Environment Energy Project although the opportunity for integrated rural development was ultimately the decisive factor.

About 25% of farm plants installed between 1989-98, as far as it is known, are still operating and in some cases being upgraded, expanded and modified to process a wider range of feedstocks including energy crops. Unfortunately, as elsewhere in Europe, a substantial number of the plants installed during these first phases suffered from operating problems and poor maintenance and have closed down while others were made redundant by enterprise changes on the farms. However, what is more important is the number that continue to operate satisfactorily 15 – 20 years since they were commissioned. Nevertheless, the dependability and longevity of these plants has been almost wholly obscured by the persistent attention that is focussed on the failures. It is a hard obstacle to overcome as it is so firmly engrained in the minds of investors, regulators at all levels and reporters in some of the national press. The commissioning of the first large scale centralised biogas plant at Holsworthy marks the end of what may be termed the foundation period and sets the context for the subsequent developments.

The current position

Between 1998- 2003 there is a noticeable hiatus in the market penetration of AD with the one exception of the Holsworthy Biogas Plant. However, the situation has changed dramatically since 2003 with the opening of 5 new plants each year and with others in varying stages of development. The demand for and construction of what have become ‘typical’ farm scale digesters (< 450 m^3) for cattle slurry continue while for the UK an entirely new generation of large biogas plants has started to develop. The plants are characterised not only by their capacity (4000- 5000 m^3) but also by the shift to co-digestion with industrial residues hitherto regarded as ‘waste’, the inclusion of energy crops with manure and the sale of electricity under the Renewables Obligation that was introduced in 2002. Developers include farm companies, local authorities, waste management companies, food processors and combinations thereof.

The period has also been marked by the development of single purpose digesters for source separated MSW and food waste driven by the need to find alternative to the disposal of bio-waste in landfills. Demonstration plants have been funded from recycled Landfill Credits or the Waste Recycling Action Plan. The facilities range in size from $600m^3$ to $3000m^3$ the latter to process the waste of large metropolitan boroughs and still larger facilities under planning.

Similar activities are also taking place under the Devolved Administrations for Scotland, Northern Ireland and Wales. The Scottish Executive funded 7 farm digesters built on land draining onto the shore of the Solway Firth to test their effect on reducing the effects of diffuse pollution on bathing water quality. In Northern Ireland development is also progressing with a number of applications submitted for part funding under the Environment and Renewable Energy Fund 2006-2008 where £15.2 m has been set aside for demonstration plants to identify and develop best practice and to assimilate renewable energy including AD through the development of effective plants. One such farm demonstration plant has just received its planning permission to address in the first instance the role of AD in dairy cow slurry and nutrient management, the assessment of life cycle benefits and mass balance (energy and nutrients), pre and post treatments and methods for enhancing digester performance. In May 2007, the Welsh Assembly announced 30% capital funding for demonstration AD plants but emphasised that tenders must demonstrate the choice of well proven suppliers and technology.

The burst of building activity looks set to continue. Market intelligence indicates that at least 30 new on farm schemes are under discussion and there are plans for further large scale plants to process vegetable, food and slaughter house waste, poultry litter etc. and others for energy crops. Danish, Swiss and German companies are also actively engaged in market research and plant development. The question must now be addressed as to what is stimulating the current growth phase.

There would appear to be are two mutually supportive drivers – the Landfill Directive and the Animal By-products regulations. Under the Landfill Directive local authorities must reduce the amount of bio-waste sent to their sites or face the prospect of a £150/t fine for non- compliance with prescribed targets the first due in 2009/10. If they have not met their obligation then they can purchase Landfill Allowances from another authority that has done so or use a buy out system known as the Landfill Allowance Trading Scheme (LATS). The growing number of MSW digesters indicates how a growing number of local authorities are now turning to AD as one of their best available technology options for meeting their targets. Furthermore, the Landfill Tax levied on all waste sent to landfill from industry, services, etc. is rising steadily towards its target of £35 per tonne such that clean food and industrial waste is becoming an attractive feedstock for new farm biogas enterprises. The combination of these two measures is acting as a 'push factor' to find alternative best available practices to dispose of waste in so far as these products are relevant to AD. This in turn is reinforced by the recognition of biogas plants that are compliant with the conditions of the animal by-product legislation as an appropriate outlet for this material. Overall however, the main driving force that underlies all this legislation and activity is the government's determination to reduce carbon emission by 60% by 2050. This will be enshrined in the Climate Change Bill currently in preparation.

The role of government

Table 2 below shows what it is suggested are the key government actions to encourage the development of renewable energy in part for security reasons but more pressingly to reduce the carbon emissions from the use of fossil fuels. Until 2005-06 these relate exclusively to electricity but thereafter consultations began for the displacement of up to a target of 5% road transport fuel with renewable sources starting from April 2008. Biogas upgraded to bio-methane to natural gas standards is included as an eligible renewable source.

It can be argued that the Energy White Paper (2003) '*Our future energy*: *creating a low carbon economy'* marks a turning point in so far as AD is concerned. It highlighted *inter alia* the failure of the renewable technologies especially biomass to penetrate the market and set up enquiries as to the reasons for the failure. Just 1.5% of total electricity production came from renewable sources and of this the biogas from landfills and sewage plants accounted for 70 % of the total output. This is despite the fact that government had placed an obligation on the newly privatised electricity suppliers in 1990 to secure 2.3% from renewable sources in 1990 when the Obligation started and to continue thereafter at a level determined by the Secretary of State. This was known as the Non Fossil Fuel Obligation (NFFO).

Table 2. Summary of legislative measures with an impact on AD

Date	Direct measures & actions	Supporting measures
1989 -1990	Electricity Act (Non Fossil Fuel Levy replaced in 1990 by Non Fossil Fuel Obligation (NFFO)	UK Animal By-Products Order limits types of food waste for biogas production following the BSE outbreak
1996 -1999		Landfill Tax and Landfill Tax Credit Scheme; Landfill Directive (1999/31/EC) to reduce biowaste sent to landfill to avoid GHG emissions
2001	Climate Change Levy on non domestic users - tax relief/kWh of RE purchased	
2002	Utilities Act replaces NFFO with Renewables Obligation and tradable Renewable Obligation Certificates (ROCs)	Animal by-products regulation recognises biogas plants with pasteurisation (equivalent), etc as an approved process (1774/2002/EC)
2003	Energy White Paper '*Our energy future: creating a low carbon economy*'	60% CO_2 reduction by 2050; highlighted low market share of renewables
2005	*'BTF report to government';* UK co-chairs with Argentina M2M Agriculture Sub Committee; Renewables Obligation Review	Landfill Allowances Trading Scheme; Electricity from AD (an advanced technology) of BDW eligible for ROCs
2006	*Government response to recommendations of BTF*	Follow up investigations by DTI et al started; M2M business meeting and Conference held in UK
2007 (May 23rd)	*'AD in Agriculture: policies and markets for growth*'; *'Economic analysis of biomass energy' 'Energy Review 2007'; Biomass Strategy*	**First official published recognition and support for AD and formal co-operation at the international level**

On the face of it, the NFFO was an attractive incentive as developers could bid at auction for a 15-year indexed linked power purchase contract. Although a number of successful bids were made for AD only the Holsworthy Biogas plant was built. The reason for the wastage lay in the bidding process. The contract price for each technology was set by the DTI and reduced year on year. In the case of AD one bidder in 1996 pitched at an unrealistically low level that then made it impossible to develop economically viable plants. Holsworthy alone proceeded as it had the benefit of a 50% capital grant awarded from EC Structural Funds. Furthermore, AD developers were restricted to 20% of the total dry matter allowed from non- agricultural sources. The NFFO achieved the government's aim in reducing the price of renewable electricity to near convergence with the pool price over the full term but it took just one bid to block the opportunities for AD. In 1997 the prospect for AD was bleak. Attempts to break into the electricity market halted but the installation of farm scale AD continued until all that had secured Farm Waste Management Grants were completed.

The outcome of the White Paper in 2003 was twofold: a shift to the **Renewables Obligation (RO)** whereby the power suppliers were required to purchase Renewable Energy Certificates **(ROCs)** or pay a fixed sum –'buy out price' -currently £35/MWh to cover any shortfall in their obligation. Electronic auctions of power without limitation to its source (wind, solar,etc) are held monthly and although the average price is about £45/MWh it can be as much as £75/MWh according to supply and demand on the day. In the main the new developments except the on farm plants in Scotland which use the gas for their own heat needs have opted for electricity enterprises under the RO with some use of the heat where the opportunity arises.

The second outcome was the Biomass Task Force set up in 2004, to establish what measures were needed to increase the market share for biomass energy. Its value for AD in particular lay in the scope that it offered through the consultation process to make the case for AD. For the first time, the biogas industry in its broadest sense to include design and construction companies, developers and prospective biogas users had the opportunity to present both oral and written evidence to demonstrate its value - a technology that had been overlooked and under valued for so long. The submissions were based on practical experience gained from many years of biogas plant design, construction and operation not only in the UK but supported by a depth of working knowledge of AD developments in Europe, was thoroughly substantiated by the wealth of research that has been carried out on productivity, feedstocks, etc and provided evidence of the UK energy potential from biogas, the Carbon Dioxide and Pathogen Reducing Effects and mineral fertiliser displacement potential that AD has to offer. Government accepted the Task Force recommendations to look further into the potential for AD and set up working groups to address the comparative economics of the biomass exploitation including AD [2]. The resulting Biomass Strategy [3] with a separate section devoted to AD and its supporting Working Papers were published (May 23rd). A clear structure has now been opened for the first time for Government to work with AD on how to advance its adoption as a multi-purpose process for the production of new marketable products energy, carbon dioxide and bio-fertiliser and as an integrated system for resource and environmental management.

Parallel with the work of the Task Force DEFRA itself has been playing a leading international role in the newly formed global partnership Methane to Market (M2M) that, in 2006, it co-chaired with Argentina [4]. In this capacity it organised a conference in November 2006 to highlight the place of AD in market growth and how to achieve it. This partnership of governments consists at present of 19 countries and each with an urgent need to reduce methane emissions from agriculture and to harness them for the benefit of local communities. Members have joined from every continent but most notably only from the eastern parts of Europe (Russia, Ukraine and Poland). M2M has focussed to date on the place of AD in agriculture for the reduction of methane emissions and the policies and market development needed for growth. The action plan now identifies the work that needs to be done [5].

The way ahead

The Biomass Strategy now provides a future for AD. It has been identified it as the preferred technology for the recovery (NB p**roduction** would have been a more appropriate term) of energy and other materials from source separated MSW. It is now recognised at government level as a well proven technology and DEFRA has started to set up meetings with stakeholders as for example the AD Committee of the Renewable Energy Association to drive faster growth for AD, stimulate markets for its products and to work with the Environment Agency for a protocol to assure the quality of the digestate as a bio-fertiliser. Collaboration through M2M with the International Energy Agency's Bioenergy Programme' Energy from biogas and landfill gas' will be used to facilitate the chance to learn from the experience in other countries. Furthermore, the operation of the

Renewables Obligation will be reviewed and also the potential for the upgrading of gas to natural gas standard whether for grid injection or use as transport fuel. In the UK is AD is definitely on the move on the move with a will to overcome the hurdles along the way!

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Treatment of pig manure for removal of residual organic matter, phosphates and ammonium

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Abstract

Full-scale anaerobic digestion of pig manure often resulted in liquid effluents with considerably high organic matter, ammonia and phosphates content. If not enough agricultural land is available, the disposal of this effluent requires additional treatment. Different process scheme for reduction of the organic matter and nutrients from thermofilically digested pig manure were tested in full-scale and lab-scale conditions. The steps tested were membrane microfiltration, anaerobic post-digestion, phosphates removal as struvite (PRS), partial oxidation and oxygen-limited autotrophic nitrification-denitrification (OLAND) process. However, microfiltration was unsuitable for treatment of digested pig manure due to membrane clogging Combination of thermophilic anaerobic digestion with sequential separation by decanter centrifuge and post digestion in UASB reactor reduced the organic content by 80 %. PRS process employing MgO for struvite formation was used for almost complete removal (96 %) of phosphates from digested pig manure. OLAND process succeeded to remove ammonium only from highly diluted digested manure with low organic matter content (around 2.5 g COD/L). Based on the results obtained, a conceptual scheme for treatment of pig manure is suggested.

Keywords:

anaerobic, digested pig manure, UASB, PRS, OLAND

Introduction

Pig farming is a major EU agricultural industry. Nowadays, farmers in the EU are confronted with an increasing number of environmental regulations concerning the application of the produced manure as a direct fertilizer on agricultural land.

Anaerobic codigestion of pig manure with other organic wastes in full-scale biogas plants offer several advantages such as renewable energy (methane) production, reducing pollution, odours and recycling of nutrients back to the soil [13]. Due to stringent environmental regulation on animal waste in European Union, digested pig manure is regarded as potential environmental risk with respect to its still high biodegradable organic matter, phosphate and ammonium content. Up until now, only process schemes for anaerobic treatment of raw pig manure containing wastewaters have been developed [2, 7, 11, 7]. Most advanced processes studied for organic matter (in means of chemical oxygen demand, COD), phosphates and ammonium removal were upflow anaerobic sludge blanket (UASB), phosphates removal as struvite (PRS, a process developed by Colsen BV in cooperation with Geochem, prof. Olaf Schuiling) (The removal of phosphates from anaerobic treated wastewater or effluent from digesters, through the production of usable fertilizer "struvite") and OLAND (oxygen-limited autotrophic nitrification-denitrification) [8] respectively. UASB reactor technology has already been demonstrated for removal of organic matter from highly diluted (to 8 g COD L^{-1}) piggery waste supernatant [11]. However this technology was not tested for direct treatment of digested undiluted manure with high COD content (more than 20 g COD L^{-1}). PRS was proved as a relatively simple and fast method compared to biological methods for phosphorus removal. Main advantage is that the nutrients (phosphates and ammonium) are also recovered as struvite (magnesium ammonium phosphate hexahydrate) which is commonly used as fertilizer. OLAND is a novel, promising, low-cost alternative to conventional denitrification systems where ammonium is converted to dinitrogen gas with nitrite as electron acceptor. It has never been used directly for ammonium removal from wastes with high organic content such as animal manures.

Up until now, a feasible process for treatment of digested pig manure is not developed yet. Innovative technologies need to be implemented in order to find sustainable solution for removal of residual organic matter and nutrients from digested pig manure.

The aim of the present investigation was to study possibility for COD, phosphates and ammonia removal from digested pig manure The processes used were membrane microfiltration and UASB process (COD removal), PRS process (phosphates removal), and OLAND process (ammonium removal)

Materials and methods

Substrate

Anaerobically digested pig manure was obtained from a thermophilic (55°C) full-scale biogas plant (Hegndal, Hemmet, Denmark). Plant treated pig manure together with small amount of fish-processing industrial waste. Effluent was collected after decanter centrifuge operated at 5000 g to separate fibers from the liquid fraction. This substrate was used separately in the experiments for removal of organic matter, phosphates and ammonia. The average characteristics of the substrate are presented in Table1.

Table 1. Characteristics of the digested pig manure

Parameters	Unit	Average Value ± SD
pH	-	8.09 ± 0.1
TS	g/l	21. 0 ± 0.9
SS	g/l	5.2 ± 1.0
COD (total)	g/l	23.0 ± 4.3
$N\text{-}NH_4^+$	g/l	3.5 ± 0.4
N-total	g/l	4.3 ± 0.08
P-total	g/l	0.7 ± 0.05
$P\text{-}PO_4^{3+}$	g/l	0.3 ± 0.02

Equipment

Submerged capillary membrane microfiltration unit (MRC SUR 2342, Mitsubishi, Japan) was installed in close proximity to biogas plant. A lab-scale UASB reactor operated in semi-continuous mode was used for COD removal. The reactor operational parameters were: temperature 55°C, total volume 334 mL, operating volume 255 mL, HRT 6 days. Reactor was inoculated with 0.05 L anaerobic granular sludge obtained from a potato factory (Kruiningen, Netherlands). Average organic loading rate of the reactor was 3.8 g COD $L^{-1}.day^{-1}$. For removal of phosphates, PRS process was employed as described elsewhere [2]. MgO was used for struvite formation.

For removal of ammonium, OLAND process was employed using lab-scale UASB reactor (250 ml). OLAND reactor was seeded with sludge from an oxygen-limited autotrophic nitrification-denitrification (OLAND) process. The inoculum was supplied by Laboratory of Microbial ecology (Ghent University, Belgium). The reactor was operated at 35°C and HRT of 1 d. For start-up, the reactor was fed with a synthetic wastewater [4] containing ammonia, nitrite and nitrate. Addition of pig manure digested to artificial wastewater was done gradually in 5 % increments to avoid inhibition of autotrophic ammonia-oxidizing bacteria to high organic loads. In order to increase the part of manure that could be treated by OLAND process, a partial aeration step was tested. This part of the research is still on-going.

Methane potential

Determination of methane potential of the digested manure was done by DTU method, where acumulated methane in the headspace of closed vials was analysed by GC [1]. Theoretical methane potential of digested manure was according Buswells formula [3].

Analyses

Analytical determination of total COD, total solids (TS), suspended solids (SS), volatile solids (VS), volatile suspended solids (VSS), total- and ammonium nitrogen, total phosphorus, phosphates and pH was carried out according to Standard Methods (APHA, 1998).

Results and discussion

Anaerobically digested pig manure had still high COD, ammonium and phosphates content (Table 1) with respect to EU environmental legislations concerning integrated pollution prevention and control [6]. In order to find a sustainable solution for treatment of this waste membrane, microfiltration method was tested first. This method is widely used for removal of soluble nutrients from particles in wastewater treatment [5].

Microfiltration was tested as a possible way to separate the digested manure into filtrate with low COD and suspended solids, containing mainly nutrients (nitrogen and phosphorus) and concentrate with high organic matter and solids content. The filtrate could be further treated to remove nitrogen and phosphorus while the concentrate could be rejected into anaerobic digester in order to maximize the methane production. A lot of technical difficulties on installation and start-up of the membrane were resolved successfully. Results obtained show that microfiltration lead to considerable reduction of TS - 50 %, total TSS- 98 %, VS – 40 %, VSS - 95 % and total COD - 30 %. Slight decreases of total phosphorus, ammonium and total nitrogen was also observed. No reduction of soluble phosphorus was noticed. Maximal obtained outflow rate was 12 L filtrate per hour. However aeration of the membrane created foaming after 12 h of operation. Complete clogging of the membrane was observed after 3-4 days of operation. Back flushing with water failed to completely remove accumulated particles. Data obtained showed that the membrane was unsuitable for practical application. This resulted in a need to find another options for treatment of digested pig manure in order to remove residual COD, ammonium and phosphates.

UASB reactor technology was tested for removal of organic matter from digested manure. In order to evaluate performance (organic matter removal efficiency) of the UASB reactor, methane potential experiments were carried out. Theoretical methane potential of the digested manure was 8 m^3 CH_4 m^{-3} waste. As the maximum methane potential obtained in this study was 5.5 m^3 CH4 m^{-3} waste, anaerobically degradable organic matter in the digested manure was around 70 %. This value was used to calculate degradable COD removal efficiency (Figure 1) according to detected COD removal values. Results obtained for steady state (Figure 1) showed high degradable COD removal efficiency, around 70 %. This proved UASB technology as a good option for organic matter removal from digested manure. Combination of thermophilic anaerobic digestion with sequential separation by decanter centrifuge and post digestion in UASB reactor resulted in 80 % organic matter removal from pig manure. This value is comparable with removal (90-95 %) of organic mater from wastewaters using UASB process (Metcalf and Eddy, 2003). However the UASB effluent had a still high organic content-around 10 g COD L^{-1} and ammonium concentration around 1 g L^{-1}. No reduction in phosphate concentration was registered. Additional treatment of digested manure was needed to reduce phosphate and ammonia levels.

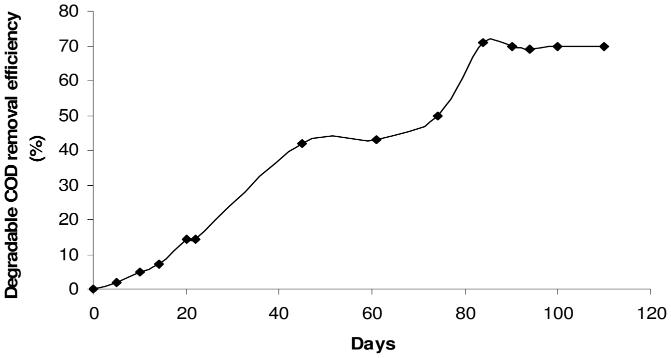

Figure 1. Degradable COD removal efficiency of the UASB reactor

PRS process was employed for phosphates removal through chemical precipitation. Results obtained showed a very high phosphate removal, about 96 %. This was in agreement with other study showed a good PRS performance for removing phosphate in the effluents from anaerobic digestion [14]. At the same time, partial ammonia and total nitrogen removal (around 6 %) was observed. According to stoichiometrical equation of struvite formation, ammonia consumption by struvite formation reaction was lower than the reduction of ammonium probably due to ammonia stripping Ammonium (NH_4) can be easily converted into ammonia (NH_3) when pH increased during chemical precipitation. COD decreased slightly over the process and practically no change in total solids and suspended solids was noticed.

For removal of ammonium OLAND process was used. In our experiments, ammonium removal varied between 80 and 90 % when up to 10 % solution of digested manure in nitrite containing artificial wastewater was used. OLAND processed failed to remove ammonium when 20 % solution of digested manure was introduced. This was due to the increased C: N ratio resulted in inhibition of the autotrophic ammonia oxidizers. Presently we are testing a partial aeration step, previous to OLAND step. This process is developed by Ughent and Colsen and is patented as NAS® (new activated sludge) process. During this step, excess organic matter will be removed and partial oxidation of ammonia to nitrite will take place. More attempts and strategies are needed in order to adapt anaerobic ammonia-oxidizing bacteria to real manure wastewaters.

On the results obtained for removal of COD, ammonium and phosphates, a principal flowchart for whole process of pig manure treatment is suggested (Figure 2). After anaerobic digestion and decantation, liquid manure fraction could be processed in a UASB reactor for reduction of residual COD combined with biogas production. The effluent from this step could further be processed for complete removal of phosphates as struvite. Finally, residual ammonium (after partial aeration step for nitrite formation) could be degraded to dinitrogen gas in OLAND process by anaerobic ammonia-oxidizing bacteria adapted to high organic loads. However, more investigations are needed to clarify the economical feasibility of such a process scheme.

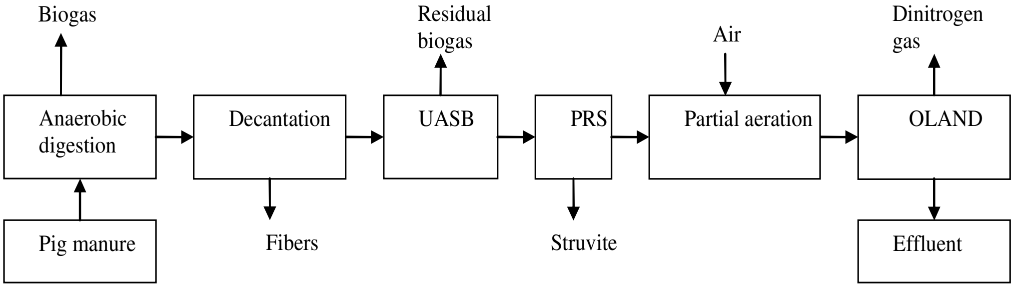

Figure 2. Principal flowchart of a possible pig manure treatment process

Conclusions

Anaerobic digestion of pig manure resulted in digested effluents with high organic matter, phosphates and ammonium content. UASB technology can be applied as a method for removal of residual COD combined with renewable energy (methane) production. PRS treatment was found to be an excellent process for almost complete removal of phosphates. However, more attempts are needed in order to find a way for adaptation of anaerobic ammonia oxidizers to high organic content of digested manure.

Acknowledgements

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Current state and new initiatives for biogas in Bulgaria

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Introduction

The paper has the goal to:

1. Summarize Bulgarian industrial-scale experience in the field of biogas and biogas technologies and the current state concerning the total number of animals, quantity of manure and potential amount of biogas production in Bulgaria.
2. Represent the long-year scientific research of a multidisciplinary team of the Institute of Microbiology of the Bulgarian Academy of Sciences over the process of anaerobic digestion (AD) of organic wastes (single and mixtures) by studying the influence of some appropriate stimulating substances and surfactants at different stages of the AD, as well as developing new models and algorithms in order to optimize and control it.
3. Present some new biogas initiatives.

Industrial experience

2.1. Podgumer biogas plant

Due to the high pollution of the river Iskar area by big cattle farms, an experimental industrial-scale biogas plant construction in the village of Podgumer (near Sofia) started by government decision in 1982 with the following parameters: treating dung from 5 000 heads of cattle; two methane tanks of 1 500 m^3; two gas holders of 500 m^3; two boilers heating 650 dm^3 water /hour; incoming organic waste per day - 141 m^3; dry matter content - 9-13%; hydrolytic retention time - 22 days; mesophilic process; daily biogas production – 2 000 m^3; biogas utilization for thermal energy production (hay drying in summer); producing manure for 400 hectares. The period of operation of this biogas plant was 1986 - 1990 (in 1991 the farm was closed down).

2.2. Biala Rada biogas plant

This biogas plant started operation in August 1989 near a big swine farm. Biogas from a 1 500 m^3 methane tank was used for hot water. The period of operation of this biogas plant was only 1 year (in 1991 the farm was closed down).

In our days there are no biogas plants in operation in Bulgaria.

2.3. Biogas from sewage treatment plants

Nowadays 38 plants with possibility for anaerobic treatment of the activated sludge (only 2 ones with operating methane tanks) are in operation in Bulgaria and about 32 plants are under construction.

Scientific research

3.1. Laboratory equipment at the Institute of Microbiology

Five anaerobic stirred tank bioreactors were used in the run of the investigation: one of 20 dm^3, two of 3 dm^3 and two of 2 dm^3. All reactors are equipped with automatic control systems to maintain mesophilic conditions (temperature 34±0.5ºC) and shielded against light. To measure the volume of the obtained biogas, every bioreactor was provided with a water-displacement gasholder.

3.2. Materials

For the purpose of the study, the following materials were used as substrates (separately and in mixtures): activated sludge from the Sofia Municipal Wastewater Treatment Plant; cattle dung; milk whey.

Surfactants. The surfactants used in this study were the biosurfactant produced by *Pseudomonas* sp. S-17 and chemical surfactant Triton X-100 (scintillation grade) purchased from Kochlight Laboratories Ltd.

Chemicals. All chemicals for the analyses were analytical grade and were obtained from commercial sources.

3.3. Methods

pH was measured by Seibold pH-meter Type G 104 equipped with Ingold 465 combined pH-electrode.

Chemical oxygen demand (COD) was determined by means of the Open Reflux Method according to the APHA Standard Methods of Examination of Water and Wastewater.

Biological oxygen demand (BOD_5) was determined by standard method and specialized device for oxygen concentration measurement.

Cell growth. The growth of two isolates was followed by changes in the optical density at 570 nm (OD_{570}) of the cultures and in the total dry solids.

Glucose. The glucose content was determined by means of enzyme colorimetric COD-PAP method using Glucosio FL single reagent from Chema Diagnostica – Italy.

The volatile fatty acids (VFA) and the ratio VFA/bicarbonate alkalinity were determined according to the Ripley method.

3.4.Results and discussion

3.4.1. AD of a mixture of two substrates

AD of mixtures of different substrates is a new trend in biogas production. It gives the possibilities to stimulate the AD of some not so easy susceptible to this process materials by mixing them with others which are easier degradable. On Fig. 1 some results of AD of a mixture of cattle dung and milk whey in different ratios are shown. The increase in the content of whey up to 75% in the mixture leads to an increase of the biogas yield, and content of 75% - 90% leads to a dramatic drop in the daily biogas production Q. The tendency to stimulation of the process with up to 75% whey in the mixture and the inhibition with up to 90% is observable in the changes of COD as well. It is obvious that there is a correlation between the higher jump in the whey content, the peak in the VFA and the drop in the biogas yield between days 80 and 160. After reverting to previous lower whey content (50%), a recover in the process is observable.

On Fig. 2 some results of the process of anaerobic digestion of a mixture of waste from industrial alcohol production and cattle dung are shown. The addition of waste of 20 % causes unstable increase in the biogas yield. A higher increase in Q is observable at waste content of 40% in the mixture. At this value of the ratio waste/cattle dung the biogas yield is more stable as well. Above this content of waste, the biogas yield decreases and the process becomes more unstable.

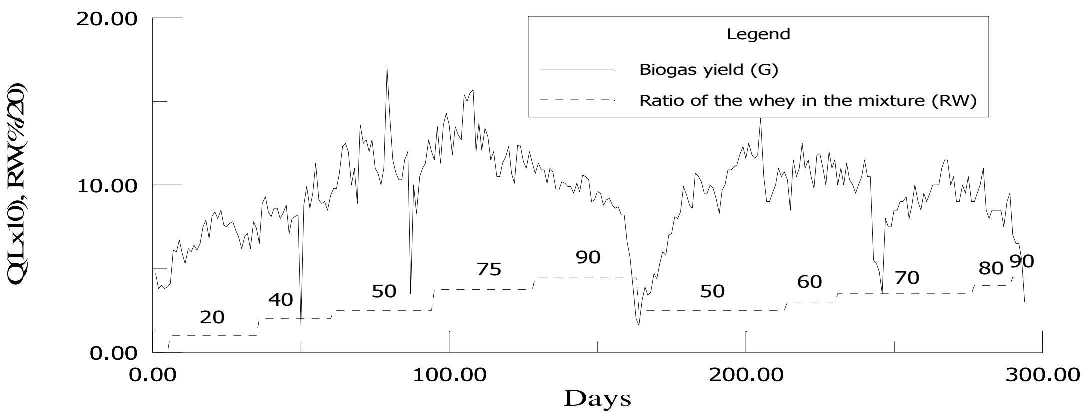

Figure 1. AD of a mixture of cattle dung and milk whey in different ratios

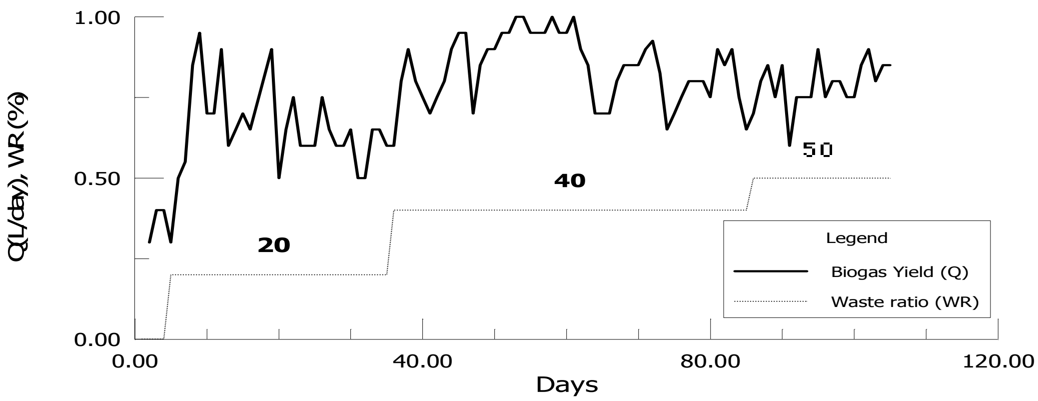

Figure 2. AD of a mixture of waste from industrial alcohol production and cattle dung

A static map for the biogas production from mixtures of two substrates is shown on Figure. 3.

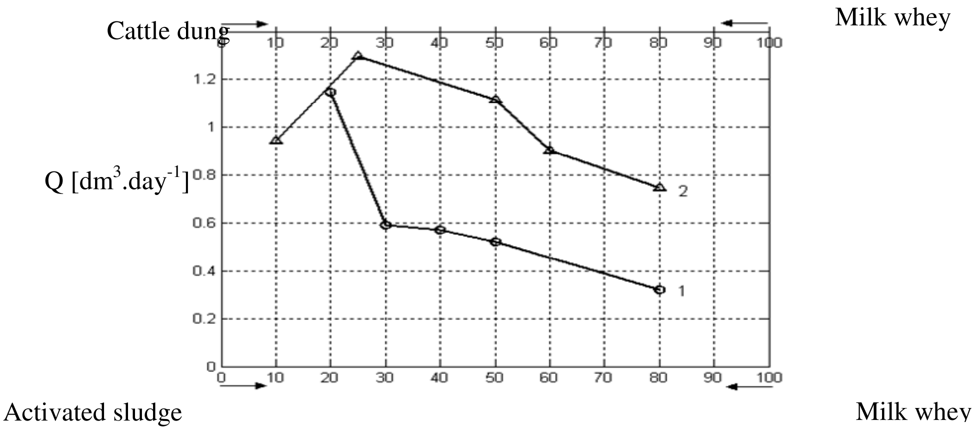

Figure 3. Biogas production with two-component mixtures
(1 – mixture “activated sludge – milk whey", 2 – mixture “cattle dung – milk whey”)

3.4.4. AD of a mixture of three substrates

A static map for the biogas production from mixtures of three substrates is shown on Fig. 4. A clear maximum for the biogas production exists for an appropriate ratio of the different substrates.

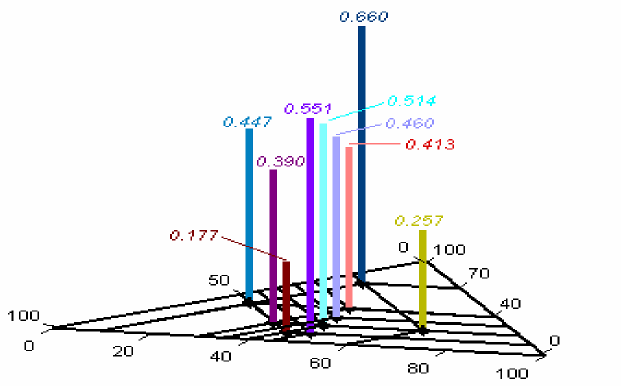

Figure 4. Daily biogas production Q [dm^3 day^{-1}]for a mixture of three substrates (D = 0.0025 day^{-1})

3.4.5. The effect of some surfactants on the process

The effects of a biosurfactant from *Pseudomonas sp*. and the chemical surfactant Triton X-100 on the growth and cell surface permeability of aerobic and anaerobic bacteria isolated from a laboratory bioreactor (1 dm^3 working volume, t=34 ^{0}C, pH=6.8, fed once daily) digesting cattle dung with 16 g COD/L were studied. Microbial growth (followed by changes in OD_{570} of the cultures) and the cell surface permeability (according to the amount of the extracellular protein) were determined in the absence and presence of the two surfactants: biosurfactant (0.06 %) and Triton X-100 (0.05%).

The obtained results showed that the action of both surfactants on the aerobic and on the anaerobic isolates was different. They stimulated the growth of the anaerobes (Fig.15) and the extracellular metabolite transport of the aerobes. These effects could be explained with the fact that the surfactants promoted cell surface changes leading to intensifying the effect of two surfactants with different origin, biosurfactant-rhamnolipid from intracellular and extracellular membrane transport of biologically active compounds.

3.4.6. Mathematical modelling and optimization of the AD

Static input-output characteristics Q=f(D) present a clear maximum for the biogas production Q for appropriate value of the dilution rate D for all AD mathematical models, as shown on Fig. 5 [2,9]. Different control and optimization algorithms based on mathematical models of the AD have been developed [1, 3-8].

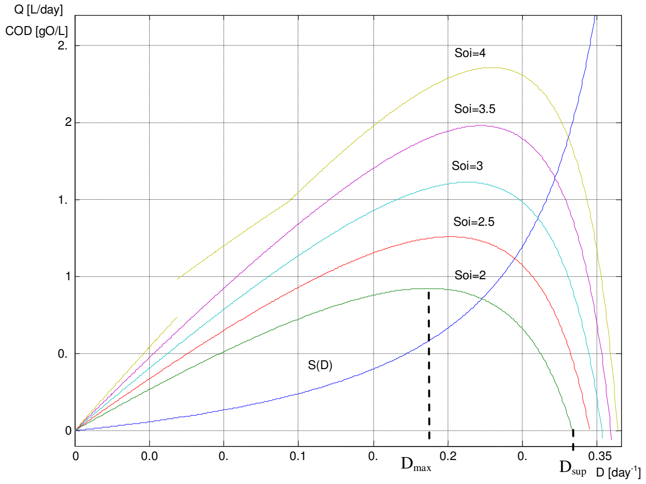

Figure 5. Static input-output characteristics for all AD mathematical models

Current state

Some information concerning the total number of animals, total quantity of manure and potential amount of biogas production in Bulgaria are shown in Table 1 and Table 2.

Table 1. Total number of animals

Type of animals	**Total number for the country** (in thousands)	**Note**
Total livestock	633,2	Towards 01.05.2006
Total swine	956,2	Towards 01.05.2006
Total poultry	17204,5	Towards 31.12.2006
Total buffalo cows	8	Towards 01.05.2006

Table 2. Total quantity of manure production

Manure's producer	**Production** (tonne / year)	**Potential biogas production** (million m^3)
Cattle	10 063 671	161
Swine	1 354 132	25,7
Poultry	1 314 684,5	30,2
Total	***12 732 487***	***219,9***

Analysing the above presented tables, one may conclude that the AD technologies are in a good position for resolving some ecological and energy problems for Bulgaria.

New biogas initiatives

In 2006 Biogas Engineering Ltd has been created. Our first important client will be the new farm in Mramoren (a village near the town of Vratza).

Technological parameters of the poultry farm in Mramoren

1. Hens: quantity – 50 000; cleaning of manure – 2000 tonnes / year.
2. Broilers: quantity – 760 000; periodical cleaning – 20 -30 tonnes dung/day.
3. Turkeys: quantity - about 250 000; 50 - 60 tonnes dung/day (periodical cleaning each 2-3 days).
4. Cows: the area within 10 km from the poultry farm can provide dung from 300 – 400 cows, i.e. about 12 tonnes of dung per day. A cow farm is expected to be built (in 1 year) in the Krivodol village, 15 km away from Mramoren, with capacity of 1000 -1200 animals (cows, calves, bulls).
5. Slaughterhouse wastes: 1 tonne blood/day.
6. Additional information:
- Own gas conductor feeding with natural gas – 20 000 m^3 /year.
- Water supply: 2 water towers, 1100 m^3 each, autonomous water conductor, capacity 950 m^3/day at technological needs 200 m^3/day.

Conclusion

Very promising perspectives exist for biogas production in Bulgaria However, we need some help from experienced industrial scale companies and financial support.

Acknowledgements

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Veterinary safety in relation to handling of manure and animal by products and the use of biogas technologies

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Over the last 30 years, cost efficient biogas production systems have been developed in Denmark, supported by governmental RD&D programmes. The results prove that biogas production by centralised co-digestion is a multifunctional technology, providing quantifiable environmental and economic benefits concerning agriculture, industry and energy as well as for the society in general. In addition it is a very competitive tool in reduction of greenhouse gas emission.

However, the technology may pose a microbiological hazard to human or animal health and to the environment by dispersal of pathogens present in the input material if these are not reduced significantly during the process. The risk is connected to the processes of collection of animal by-products (ABPs) incl. animal wastes (manure, slurry etc.) of different origins, treatment at a central biogas plant and disposal of the digest at agricultural land. The potential hazards include zoonotic agents (bacteria, parasites, fungi and possibly some viruses that are transferred from animal to man and may cause disease in humans) and animal pathogens (specific viruses, bacteria and parasites that may cause animal disease). In addition the material may contain toxigenic micro organisms, which can result in the production of microbial toxins and other potentially toxic metabolites, and also plant specific pathogens.

Which microorganisms or toxins that actually may be present in the input material depend on the kind and origin of the material used and have to be identified through actual hazard analysis. In general, the microbiological flora including pathogens will reflect the zoo-sanitary status and animal health of the domestic and wild animal populations in the area of origin. The risk of handling animal waste and ABPs of local origin will therefore be lower than handling materials imported from other areas. In the first case the potential hazards will be those already existing in the area whereas in the second case, there will be a risk of introducing new pathogens. In Denmark, for example, Salmonella occurs with a significant, albeit low, frequency in the domestic animal production and further spread of this pathogen through insecure handling of animal wastes and ABPs will have a minor impact on the economy whereas spread of e.g. Classical Swine Fewer introduced and spread by insecure handling of imported ABPs will have huge economic impact on the society (Stockmarr & Baggesen, 2007).

Different factors are important in relation to the significance of the hazards and the reduction of risk through the biogas proces. The initial concentration of the microorganisms and viruses causing the hazard can vary greatly. Some agents, e.g. viruses, can occur in very high concentrations in animal tissues and ABPs during active infection. Relatively high concentrations of viruses may also occur even in the absence of clinical and pathological signs. However, viruses, which need the living cell, are unable to multiply in ABPs. On the other hand, bacteria and fungi are sometimes able to multiply in raw materials leading to high concentrations and/or toxin production.

During the processing in biogas plants, the identified hazards from the raw material should be inactivated so that the disposal of the output material does not constitute a risk for animal or public health. Non spore-forming bacteria as *Salmonella* and *E. coli* can be inactivated at temperatures between 55 and 100°C whereas the inactivation of spores of spore-forming bacteria (e.g. *Clostridium* and *Bacillus)* is much more complicated and needs a more severe processing. Some spores thus need a processing at temperatures above 120°C to be inactivated. Most parasites are fairly easy to inactivate, but eggs of parasites are quite difficult to inactivate and need high temperatures or change in pH or both. For viruses partial inactivation can occur as a result of storage; however small viruses can survive for several decades in the environment. Besides of this, viruses can be inactivated as a result of heating temperatures between 50 and 95°C, and by low or high pH depending on the type of the virus (Annon., 2005). If all potential hazards of raw material should be covered, a treatment of 133°C and 3 bar pressure for at least 20 min. has to be applied in a stirred batch process (Annon., 2005).

Heat treatment during or combined with the biogas process results in a reduction of the different pathogens present in the biomass but not in a sterilisation. The magnitude of the reduction will depend on the temperature and pressure and the process time as well as the kind of pathogen and the level of pathogens in the raw material. The reduction of a specific pathogen can be described by the dissemination-time (D_{90}), which is the treatment time at a given temperature resulting in a 90% reduction of the pathogen compared to the initial level. For ensample, the D_{90} for *Salmonella* Typhimurium is 2.4 days at 35 °C and 0.7 hours at 53 °C whereas no reduction at either of the two temperatures could be measured for *Clostridium* (Olsen & Larsen, 1987). The D_{90} for Aujeszky's disease virus is 5 hours at 35 °C and 10 minutes at 55 °C (Bøtner, 1991).

In order to control the potential risk towards animal and public health due to treatment of manure and AMPs in biogas plants, EU-legislation has been established. Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 thus lays down health rules for the collection, transport, storage, handling, processing and uses or disposal of ABP's not intended for human consumption. In this regulation specific rules for management of biogas plants including specification of raw materials and of time and temperature for treatment are given. The regulation has later been revised and rules for evaluation of alternative managements has been added.

In general, all biogas plants have to be approved by the competent authority. A risk assessment on end product and control of the process applied should be carried out for all processes to be used. A hazard analysis (HACCP) must be made to identify the hazards and any critical control points in a particular situation. The intended process must then be validated to confirm the risk reduction. Thereafter, a complete control programme should be designed including procedures for monitoring the process. Operation of the plant requires continuous monitoring and supervision of the relevant process parameters (e.g. time and temperature) fixed in the control programme. In the legislation, treatment of raw material with a maximum size of 12 mm at 70 °C for 60 min. is prescribed. However, the national authorities and EU can approve alternative procedures if they are validated "*lege artis*" and the validation shows that the process achieves certain minimum criteria such as: (a) reduction of 5 log10 of non spore forming pathogenic bacteria, of parasites and of non-thermoresistant viruses (b) reduction of infectivity titer of thermo resistant viruses by a minimum of 3 log10 (c) reduction of parasites by at least 99.9 % (3 log10) of viable stages (Regulation (EC) No 1774/2002).

The risk analysis of spread of disease in relation to handling of animal wastes and by-products should cover the whole chain from collection of waste at animal production, import of other raw materials as ABPs, transport, treatment at biogas plants, storage, transport and disposal of manure (Figure 1). The evaluation of the overall risk of spread of pathogens should be based on evaluation of the probability for survival or transfer at each level of the chain. Unfortunately, these probabilities are not always known, and therefore risk analyses of different risk scenarios may be conducted, where scientific knowledge is combined with experts' opinions to provide estimates for the risks in the different scenarios. In addition it is in most cases not possible to establish the exact probability of disease transmission, whereas the relative difference risk (in terms of the ratio between risks) at different scenarios are used in the analysis. In this situation, the risk analysis may be used for evaluation of differences in risks between different situations. In a Danish research project, the risk of spread of Salmonella after application of different well established and new biogas strategies (reference) for treatment of manure was analysed as a model for an overall evaluation of the risk of disease transmission between animals through manure (Stockmarr & Baggesen, 2007). In the project different scenarios were analysed and especially focus was put on whether mechanically handling of material ("drop off") or disposal of material at the field constitute the most important risk for reintroduction of pathogens to a non infected animal herd. In a scenario where the highest risk of spread of infection was related to spread of contaminated material at the field, application of biogas strategies – both well established and new strategies – gave a reduced risk for spread of infection compared to handling of manure without biogas treatment. In contrast, in scenarios where the risk for spread of infection mainly was related to mechanically handling, the application of biogas treatment increased the infection risk due to the more intensive handling of the materials. The risk analysis therefore demonstrate that correct application of biogas technologies taking the necessary measures to ensure the sufficient hygiene level can improved the animal and public health but also that this benefit can be lost if the hygiene is not sufficient (Stockmarr & Baggesen, 2007).

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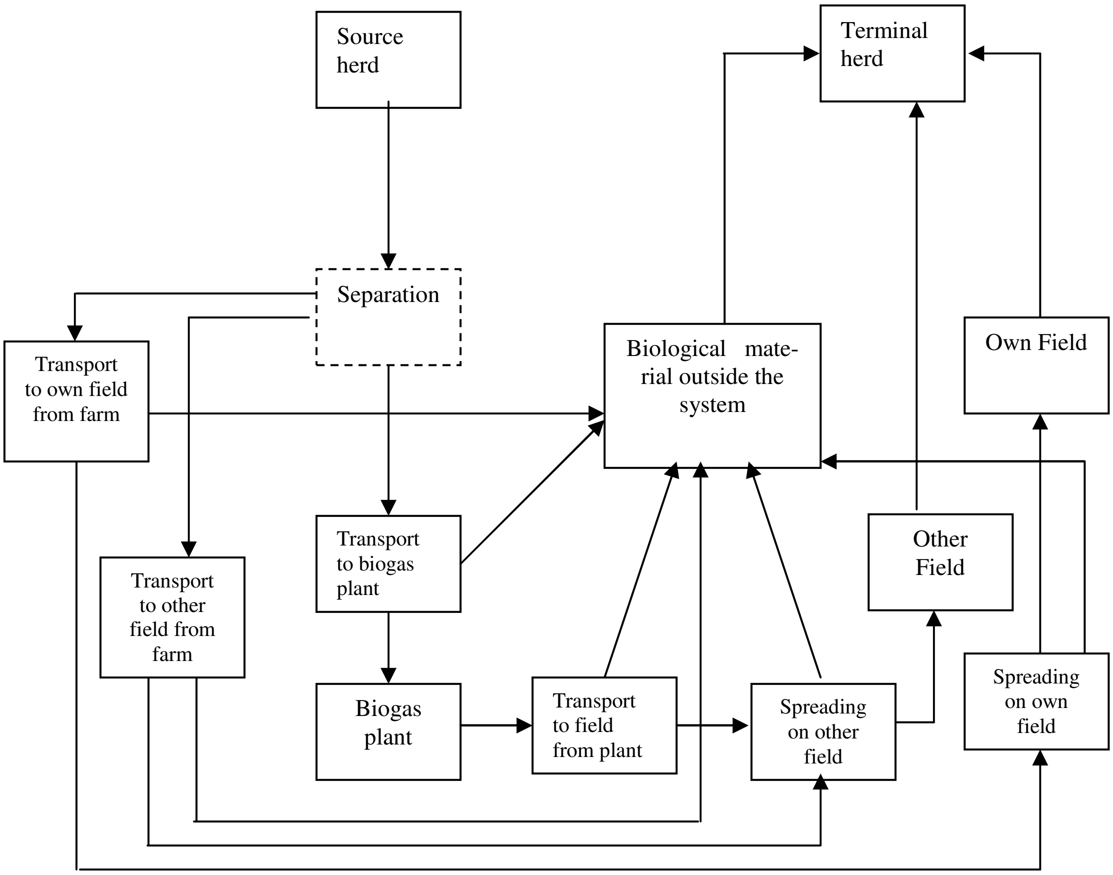

Figure 1. The chain from collection of waste at animal production, import of other raw materials as animal by-products, transport, treatment at biogas plants, storage, transport and disposal of manure.

Digested manure is a valuable fertilizer

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Abstract

In Denmark digestion of slurry is recognized to contribute to a better utilization of the slurry as a plant fertilizer. From a large number of field trials this has been documented. It is also evident that digestion reduces the smell problems after spreading the slurry.

Introduction

In Denmark biogas production is resting on three legs: energy production, agricultural advantages and a purer environment. If you saw off one leg, the whole construction will tip over! A biogas plant is located in the intersection between the three legs. If the plant is correctly located and all three legs carry equal weight, large synergy effects can be achieved for the benefit of agriculture, the environment, the energy sector and thus the surrounding community.

Biogas provides many advantages

Over the last 12-15 years Denmark has made determined efforts to promote biogas production based on codigestion of animal manure and organic waste. The normal procedure in Denmark is to codigest about 75 per cent animal manure with about 25 per cent organic industrial and domestic waste. By far most organic waste originates from the industrial sector [1].

In the course of this period a wide range of advantages has been demonstrated which does not necessarily concern energy production (table 1). Some experts might almost claim that energy production is of secondary importance! The following paragraphs describe the most important advantages from an agricultural and an environmental perspective.

Table 1. Advantages of biogas production for the energy sector, agriculture and the environment. In **bold** the issues especially discussed in this paper

Energy sector	Agriculture	The environment
• energy production • CO_2 neutral	• **improved utilisation of nitrogen from animal manure** • **balanced phosphorus/** • **potassium ratio in slurry** • **homogeneous and light-fluid slurry** • reduced transportation of slurry • possible to get large - amounts of slurry with a full declaration of contents • slurry free from weed seeds and disease germs	• reduced nitrogen leaching • **reduced odour problems** • reduced greenhouse gas emissions • controlled recycling of waste

What is digested slurry?

Digested slurry must be transported, stored and spread in the same way as slurry that has not been used for biogas production. However, there are some important differences. The distinctive features of digested slurry are:

- that several types of slurry and waste are mixed
- that the organic matter of slurry is partly degraded

Table 2. Content of dry matter, nutrients etc. in slurry used in field trials at Danish Agricultural Advisory Service in 1999-2001. In () the number of samples are indicated. The digested slurry used is likely to be a digested mixture of about 50% pig slurry, 25% cattle slurry and 25% organic industrial waste. [4]

	Dry matter, %	N-total, kg per tonne	NH_4-N, kg per tonne	P, kg per tonne	K, kg per tonne	pH factor	NH_4-N-share, %
Digested slurry (20)	4,8	4,4	3,5	1,0	2,3	7,6	81
Pig slurry (28)	5,0	4,8	2,9	1,1	2,3	7,1	74
Cattle slurry (15)	7,5	3,9	2,4	0,9	3,5	6,9	61

To consider the nutrient value of nitrogen it is important to notice that:

- the dry matter is relatively low in digested slurry due to the degradation in the biogas reactor. This makes the slurry more liquid.
- the ammonium (NH_4-N) content is higher than in untreated slurry due to degradation of organic bound nitrogen in the reactor.
- the pH factor rises due to degradation of organic acids in the slurry. This increases the risk of ammonia volatilization.

Photo text: Biogas plants contribute to a better utilization of nutrients in the agriculture. Photo: Torkild Birkmose, DAAS

Digestion increases the fertilizing effect of slurry

The physical and chemical process taking place in the biogas plant changes the fertilizing effect of the slurry in the field. It is important to make allowance for this when the fertilizing plans are prepared and also when handling and spreading the slurry. In the planning process the high content of ammonium has to be considered. This high content is advantageous to the crops as they are primarily capable of utilising ammonium nitrogen. In other words: It is often possible to replace nitrogen from commercial fertiliser by digested slurry and thus save money [6].

The thin, low-viscosity digested slurry seeps relatively quickly into the soil. This reduces the normally very high risk of ammonia volatilization. Trials have shown that the ammonia evaporation from surface applied digested slurry actually is lower than from surface applied pig slurry [2].

Field trials with digested slurry in winter wheat have demonstrated nitrogen utilization higher than pig slurry and much higher than cattle slurry (figure 1). This means for example that if a farmer fertilizes a field of winter wheat with 170 kg of total nitrogen in digested slurry in stead of 170 kg of nitrogen in cattle slurry, he can save about 54 kg of nitrogen of mineral fertilizer and still get the same yield!

By reducing the supply of nitrogen in mineral fertilizer a reduction in nitrate leaching can be expected. The specific reduction is dependent on the autumn and winter cover of the fields, the soil type etc. In general a reduction in nitrate leaching of 0.33 kg nitrate-N per kg reduction in nitrogen in mineral fertilizer was used in the evaluation of the second Danish environmental protection plan [3].

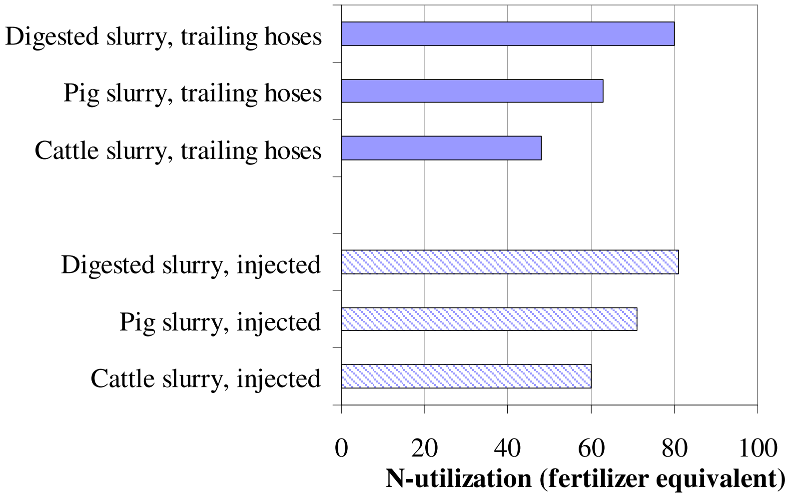

Figure 1. Utilization of nitrogen in digested slurry compared with pig and cattle slurry in field trials at Danish Agricultural Advisory Service. Average of 11 trails with digested slurry, 15 trials with pig slurry and 15 trials with cattle slurry. [4,5]

Phosphorus and potassium

The utilization of phosphorus and potassium in animal manure is normally a matter of avoiding oversupplying the crops. The best solution is only to supply until the requirement of for instance phosphorus is covered. If the requirement of potassium is not covered at the same time extra potassium in mineral fertilizer must be supplied.

The phosphorus/potassium ratio of digested slurry is often about 1:3. This ratio is excellent for crop rotation schemes including for instance grain and rape - these crops often require about 20 kg phosphorus and about 60 kg potassium. Crop rotation schemes dominated by roughage crops require extra potassium from commercial fertiliser as the demand for potassium is much higher in for instance grass, beet and maize, than in cereal and rape. If a relatively large share of the slurry to the biogas plant originates from cattle the phosphorus/potassium ratio of the digested slurry will be considerably higher, and the slurry will be more suitable for roughage crops.

Digestion reduces the smell from the slurry

In a biogas reactor almost all easily degradable organic compounds are degraded and converted into biogas (methane). Amongst these compounds are a lot of volatile organic compounds that smell very bad. For example a great number of fatty acids. When these compounds are degraded, the smell will be reduced compared to untreated slurry after spreading on the fields. In figure 2 the content of four fatty acids in untreated and digested pig slurry is shown. A significant reduction is demonstrated.

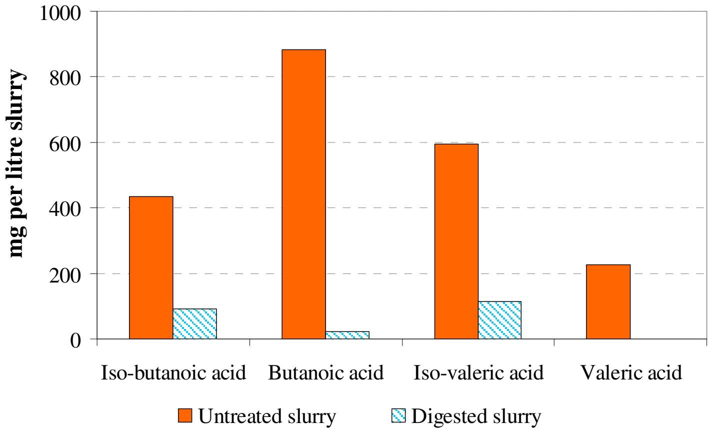

Figure 2. Concentrations of four very bad smelling volatile fatty acids in untreated and digested slurry [2]

Final remarks

The agricultural and environmental advantages of digesting slurry and organic waste are so manifold that digestion should have much higher priority. It is a paradox that only about 6 percent of all animal manure in Denmark is used to produce biogas.

Some of the reasons for this relatively low percentage are poor and unstable economy and a large administrative workload in the period of establishing (the plants are typically planned and established by farmers and it often takes 3 - 4 years from the first plans are made to the biogas plant is operational).

Even though production of electricity is subsidised (guarantied price of 0.08 EUR per kWh) and heat can be sold without tax calculations show that the plant cannot be run economic profitable in the long run. Furthermore it seems very difficult to find suitable areas to build biogas plants in order not to disturb neighbours with odour from the plant. Even though it is evident that a plant can be build with no or only insignificant odour emissions biogas plants have a bad reputation in the public.

Higher subsidise, implementation of efficient odour reduction means and hard work to improve the reputation of biogas plants in the public seems to be key words to a further increase in the number of biogas plants in Denmark.

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Further technical development and economic sustainability of co-digestion

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Introduction

The paper is related to a recently finished research project "Future Biogas Plants – New systems and their economic potential". The main results are published in (Christensen, J. et al 2007).

The project is implemented by a group of researchers from different disciplines. It is not possible in this context to cover all aspects and the presentation will concentrate on systems description and the economic results.

The main objective of the project was the identification and analysis of new technical concepts for centralized biogas plants, which would make them less dependant on organic waste supplies, and thus be economically self sustained mainly on manure supplies.

Systems and scenarios

The analyses have been carried out as system analyses, where plant concepts have been evaluated in connection with agricultural areas. 8 scenarios were analyzed, of which 2 were reference scenarios. One without a biogas plant, but with on-farm separation in order to reach phosphorous balance in the area by exporting fiber fraction (Scenario 0) to other regions, and one with a conventional centralized biogas plant with a post separation facility, likewise to enable the export of surplus phosphorous (Scenario 1).

The remaining 6 scenarios are:

1a. **Serial digestion** in two digesters, and partial **post separation** of digested manure so phosphorous balance in the area is obtained.

1b. Conventional centralized biogas plant, **post separation** and **recycling** most of the **fiber fraction**. Export of fiber fraction till phosphorus balance in the area is obtained.

2. **On farm separation** of major parts of pig manure. Fiber fraction supplied to the biogas plant and mixed with remaining conventional slurry until a **dry matter content of 10% in the biogas plant** has been reached. The thin fraction remains on the farms and is utilized as a fertilizer. **Post separation** of the digested manure, **pre treatment** (wet oxidation) and **recycling** most of the **fiber fraction** to the digesters. The remaining fiber fraction is exported until phosphorus balance in the area is reached. Appendix A shows an outline of this scenario.

2a. Same as 2, but **pressure boiling** of the fiber fraction in stead of wet oxidation.

2b. Same as 2, but **no on farm separation**, which means that the entire manure amount in the area is supplied to the biogas plant.
2c. **On farm separation** until **10% dry matter content in input** is reached, no pretreatment but post separation until phosphorus balance in the area is obtained.

In the analyses dry matter contents are used as they are found in practical Danish agriculture.

Relatively large plant dimensions have been assumed. In scenarios 0, 1, 1a and 1b, where on farm separation is not included, the manure quantities in question amount to 700 tonnes per day, which equals the amount in the agricultural area looked upon. In scenarios 2-2c 1000 tonnes per day are found in the agricultural area, but this amount is only supplied to the plant in scenario 2b. In 2, 2a, and 2c which include on farm separation, only 480 tonnes are supplied to the plant on a daily basis, which makes the average dry matter content amount to 10%.

As far as agricultural issues are concerned the scenarios are equalized in the sense that surplus phosphorus is always exported to other regions in order to obtain phosphorus balance in the agricultural area looked upon. By adjusting fertilizer purchase, the need for nutrients is ensured. In this way increased fertilizer values from the digestion process are accounted for. Equal crop rotation and harvested yields are assumed in either scenario. The well-known effect from the digestion of nitrogen utilization is found, but only little further effect may be expected from further pretreatment and separation.

The main purpose by the outlined methods for manure treatment is to increase biogas yields. The yield levels used in the analyses are partly found from literature studies, partly from lab- or pilot scale trials, accomplished as a part of the project. For different scenarios following methane yield levels are estimated.

Scenario	Dry matter in input, %	Treatment	m^3 CH_4/ tonne input
1	5,4	None	12,1
1a	5,4	Serial digesters	13,3
1b	5,4	Recycling of fibers	13,2
2	10	Wet oxidation of recycled fibers	25,1
2a	10	Pressure boiling of recycled fibers	24,7
2b	5,4	Wet oxidation of recycled fibers	14,6
2c	10	On farm separation, no treatment	20,8

Source: Input – output relations have been estimated by Henrik B. Møller, Faculty of Agricultural Science, University of Aarhus and Hinrich Uellendahl, Bio-Centrum, Technical University of Denmark.

It appears that the largest effects are reached by concentrating dry matter content via on farm separation. Between scenario 1 and scenario 2c the only difference is on farm separation, which increases methane yields from 12,1 to 20,8 m3 methane per tonne input. Serial digesters (1a) and fiber recycling (1b) increase yields by 10% and wet oxidation of fibers approx. 20%. Highest yields are obtained when on farm separation is combined with wet oxidation (2) or pressure boiling (2a), which compared to the conventional centralized biogas plant (1) more than double methane yields. The economic analyses will clarify if yield increases are able to match the cost increase that must be expected when dry matter contents are increased and different pre treatment technologies are introduced. ‘

Main conclusions

Results from the economic analyses are listed below.

Scenario	On farm separation	Post separation	Pre treatment	Farmer`s part DKK/tonne input	Biogas plant part DKK/tonne input	Total system DKK/tonne input
0	+	-	-	49	-	49
1	-	+	-	39	29	68
1a	-	+	Serial digesters	39	25	65
1b	-	+	Recycling of fibers	40	28	68
2	+	+	Wet oxidation of recycled fibers	49	18	58
2a	+	+	Pressure boiling of recycled fibers	49	24	60
2b	-	+	Wet oxidation of recycled fibers	39	27	66
2c	+	+	On farm separation, no treatment	50	19	59

Farmer’s part includes manure storage and spreading costs, on farm separation and purchase and spreading of chemical fertilizer. In scenario 0 export of surplus fibers is also included. Biogas plant part include in and out transport of slurry, in transport of fibers, export of surplus fibers (phosphorus), fiber treatment, post separation and cost and sales in the biogas plant itself.

Key figures for farmer’s part and total system are related to total manure amount in the area, while figures for the biogas plant part are related to the amount supplied to the plant, which is somewhat lower in scenarios where on farm separation is included. For that reason only in scenarios without on farm separation the figures may be added with no further notice. The biogas plant part only refers to the economy of the biogas plant, where agricultural effects are not taken into account.

Main conclusion from the economic analyses is that it is possible by on farm separation and pre treatment at the biogas plant to improve economic performance of the system as a whole and thereby decrease the need for admixture of organic waste, or other high yielding biomasses.

On the other hand the increase in economic results does not enable plants to be economic compared to the situation with no biogas plant (0). If so net costs of the total system should be lower than 49 DKK pr. tonne manure in the area, which is not the case, according to the calculations.

In fact three scenarios produce equal results; scenario 2c with on farm separation, scenario 2 with wet oxidation and scenario 2a with pressure boiling. Scenario 2b where on farm separation is not included, but wet oxidation is included, is found to produce equal results as scenario 1, the traditional centralized biogas plant. The only favorable scenario with no on farm separation is scenario 1a, with serial digesters.

Farmers costs are lower in scenarios where no on farm separation takes place, as it is assumed that the biogas plant carry the costs for post separation and export of surplus fibers.

In general, costs in the biogas part are lowest, when dry matter contents have been concentrated to 10%, but as it appears, they are not too close to zero, which is the point of economic feasibility.

So it has to be concluded that supplies of organic waste, which lead to increased income by treatment fees and increased biogas production still is necessary. But some technical concepts, where a treatment of fibers takes place to increase methane yields, seem to decrease the dependence of organic waste.

Sensitivity analyses show that a treatment cost reduction via technological development will of course contribute, but it is unlikely that this can ensure economic operation based solely on manure. Further it is not likely that pre treatment can increase methane yields to an extent that it will ensure economically viable operation.

With the assumptions made, farmer's advantages will be limited. They depend on the assumption that it is possible to organize on farm separation in the area to a considerable extent without establishing a biogas plant, and that it is possible to export surplus fibers to other regions. If these preconditions cannot be met or if the need for nutrient export is higher, in order to protect environmentally vulnerable areas or fresh water systems, this could be different.

It would hardly be easy to convince many farmers in the area that on farm separation is a good idea unless the fiber fraction is easily exported. But the biogas plant may receive the fibers, and by that increase dry matter supplies to the plant and achieve increased energy production. From the biogas plant point of view, the problem is that not all the nutrients can be returned to farmers in the area, but have to be exported to crop producers in other regions. It may be easier to organize this export via the biogas plant by joint efforts. The possibility of disposal to incineration or further concentration of nutrients may likewise be easier due to larger amounts on hand.

Calculations do not show the mentioned issues. If scenario 0 is unrealistic, costs may be much higher, and a worst case calculation could be based on costs by livestock reductions due to increased environmental restrictions.

Today the possibilities and costs by exporting surplus manure or fibers form a barrier for on farm separation. This may be seen as an increase in the competitiveness of centralized biogas plants. But of course only to the extent that livestock producers are willing to pay a treatment/export fee, or alternatively carry the costs of on farm separation.

Perspectives for biogas business

Initiatives to improve economic performance of biogas plants must be of interest for those who operate biogas plants, those who plan the establishment of new plants, equipment suppliers and advisors.

Some results of the project are still uncertain, and specific recommendations for their introduction can not yet be given. Wet oxidation and pressure boiling strongly need further research, development and testing before these technologies can be recommended for practical use. This is due to the fact that they demand considerable investments, and the uncertainty about methane yields, operation strategies and costs. On the other hand, results are so promising that they deserve to be tested under conditions close to a practical situation. This may be accomplished in connection with the full scale test facility, which is under construction by Faculty of Agricultural Sciences in Foulum.

Other results seem closer to practical introduction. Considerable effects are found by on farm separation, supply of the fiber fraction to the biogas plant, and thereby increase the dry matter content, and thereby the energy production potential. This is especially true if farmers are willing to carry the costs of separation in return for the benefits they gain in cost savings from nutrient export and the possibility to breed more animals per area unit.

Testing of systems that include source separation in animal houses have been initiated, and if they turn out advantageous, separation costs may be lower than estimated in this project. Further, supply of fiber fraction is also an option for existing biogas plants.

Post separation at the biogas plant may take place no matter if previously on farm separation took place. Post separation should partly be seen as a part of recycling of fibers, and partly as an effort in the disposal of surplus nutrients, especially phosphorus. Either to crop producers outside the area covered by the biogas plant, or for incineration or further concentration of nutrients. The advantage is that a much larger amount is available, and separation unit costs will be lower than by on farm separation.

Serial digesters or prolonged retention time, or possibly in combination with on farm separation, should also be relatively easy implemented if plants control more than one digester or have surplus capacity. The latter could be achieved by on farm separation, where the thin fraction is left on the farms, by which capacity in the digesters is made available.

As mentioned earlier it is not likely that separation and treatment of fibers enable centralized biogas plants to reach economically viable operation solely on the basis of manure under Danish conditions. But results from this project shows that it is possible to approach such situation. Plants will prove more resistant to failing waste supplies. But if waste supplies are maintained as usual, economic performance will be further improved.

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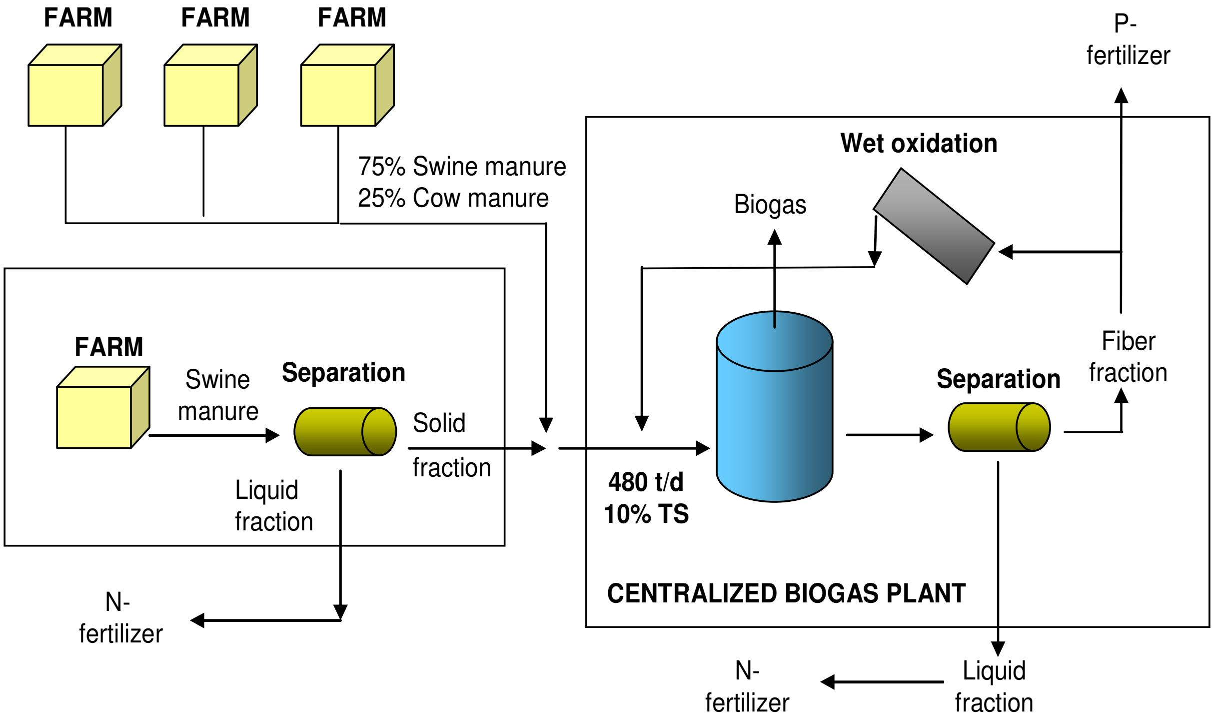
Appendix A

Scenario 2. On farm separation, wet oxidation of post separated and recycled fibers



The Future of Biogas in Europe: Visions and Targets until 2020

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Introduction

Biogas can be produced of nearly all kinds of organic materials. It is closely linked to agricultural activities and human consumption. Wherever there is a large population, and thereby a comprehensive quality food production of a broad mixture of vegetable and animal foods, the right conditions exist for biogas production. In the future the large volume of biogas will be integrated into the European farming systems. There are quite a few biogas process volumes at the current wastewater treatment plants, landfill gas installations, and industrial biowaste processing facilities. However, the largest volume of produced biogas will, by 2020, originate from farm biogas and from large co-digestion biogas plants, integrated into the farming- and food-processing structures.

The EU policy concerning renewable energy (RES) has set forward a fixed goal of supplying 20% of the European energy demands from RES. It is without doubt, that a major part of the renewable energy will originate from European farming and forestry: as biomass conversion to gaseous, liquid and solid biofuels. The gaseous part – the biogas production - has its own, more and more consolidated platform. The forecasts look promising. At least 25% of all bioenergy in the future can originate from biogas, produces from wet organic materials, like animal manure, whole crop silages, wet organic food/feed wastes etc. The forecasts for a very flexible utilisation of biogas are prosperous, but it implicates that the biogas is to be cooled, dried, cleaned and upgraded to natural gas quality, in order for the application and utilisation routes to be plentiful.

Biogas resource bases;

Energy crop potential

In the presented predicted energy crops potential, general units of energy are used. It is not indicated, whether the biomass will be converted into fuel, electricity, or any other form. For simplifying the calculations, it was assumed, that the heating value of 1 kg dry matter biomass is equal to 18 MJ. For further recalculations, 1 Mtoe (mill tonnes of oil equivalent) is equal to 44.8 PJ. Heating value of methane is equal to 40.3 MJ per $m^3 CH_4$.
All the data concerning total area, agricultural and arable land are taken from the FAO database (2003) (FaoStat). The eventual changes in land use (decrease or increase of arable land) are not taken into consideration. All the calculations are based on “today’s” arable area.

Table 1 contents registered data of total area of land use for 27 European countries (EU-

27). Data shown for the areas of specific interests for biomass production conditions are the total agricultural area and arable land. It is important to underline that forest and permanent grassland might be partly interesting for future energy farming, specifically the forestry areas. The fallow areas might also soon be integrated in arable land or non-food areas. The calculation of biogas potential was taken into consideration only on arable land.

Table 1. Data of total area and areas of interest for biomass production for each member of EU-27; area data in millions of hectares (Holm-Nielsen, et al, 2006)

	Total area (10^6 ha)	**Agricultural area (10^6 ha)**	**Arable land (10^6 ha)**	**(% of total area)**	**Hectares of agricultural land per capita**
Austria	8.4	3.4	1.4	17	0.42
Belgium	3.1	1.4	0.8	27	0.13
Bulgaria	11.1	5.3	3.3	30	0.68
Cyprus	0.9	0.1	0.1	11	0.18
Czech Republic	7.9	4.3	3.1	39	0.42
Denmark	4.3	2.7	2.3	53	0.49
Estonia	4.5	0.8	0.5	12	0.63
Finland	33.8	2.2	2.2	7	0.43
France	55.2	29.7	18.5	33	0.49
Germany	35.7	17.0	11.8	33	0.21
Greece	13.2	8.4	2.7	20	0.77
Hungary	9.3	5.9	4.6	50	0.60
Ireland	7.0	4.4	1.2	17	1.09
Italy	30.1	15.1	8.0	26	0.26
Latvia	6.5	2.5	1.8	28	1.08
Lithuania	6.5	3.5	2.9	45	1.02
Luxemburg	0.3	0.1	0.06	24	0.28
Malta	0.03	0.01	0.01	31	0.03
Netherlands	4.2	1.9	0.9	22	0.12
Poland	31.3	16.2	12.6	40	0.42
Portugal	9.2	3.7	1.6	17	0.37
Romania	23.8	14.7	9.4	39	0.66
Slovakia	4.9	2.4	1.4	29	0.45
Slovenia	2.0	0.5	0.2	9	0.26
Spain	50.5	30.2	13.7	27	0.73
Sweden	45.0	3.2	2.7	6	0.36
U. K.	24.4	17.0	5.7	23	0.28
EU-27	**433.1**	**196.6**	**113.5**	**26**	**0.41**

Based on the data from the Table 1, the possible energy crops potential was calculated. The results in PJ and Mtoe are presented in Table 2. The countries with good potential to produce biomass for energy are the ones with high ratio hectares of agricultural land per capita. The new member states: Bulgaria and Romania, with high hectares of agricultural land per capita (both almost 0.7), could make the development and implementation of EU bioenergy policies easier. The average of the EU-27 is 0.4 hectare/capita.

Table 2. Energy crop potential in EU-27, depending on percentage of utilized arable land and achieved crop yield

Yield	10% arable land in EU-27		20% arable land in EU-27		30% arable land in EU-27	
10 t TS/ha	2,042 PJ	46 Mtoe	4,084 PJ	91 Mtoe	6,127 PJ	137 Mtoe
20 t TS/ha	4,084 PJ	91 Mtoe	8,169 PJ	182 Mtoe	12,253 PJ	274 Mtoe
30 t TS/ha	6,127 PJ	137 Mtoe	12,253 PJ	274 Mtoe	18,380 PJ	410 Mtoe

In the coming 10-20 years an increasing utilisation of crops for energy and industrial purposes is expected to be seen. Scenarios of 10-20 or 30% of the arable land shifting from food and feed towards energy farming will gradually occur. Large European countries, with significant fertile agricultural area of cropland, might play a major role in bioenergy production; examples can be Ukraine and France. The average total crop yield of around 20t TS/ha is considered feasible in the near future. According to Perlack et al., the average yields for switchgrass clones, tested in several places in the US, varied from a low 10 total solids per hectare to a high 25 total solids per hectare, with most locations having average from 13 to 20 tTS/ha. These results indicated that future yields could be estimated to 20 tTS/ha.

The above values were calculated for complete combustion of the biomass. The biogas conversion efficiency can be assumed for 80% due to the fact that not all of the compounds from biomass can be digested through AD process like the lignin. Table 3 presents recalculated energy crop potential in amount of produced methane through anaerobic digestion process. Furthermore, it has to be taken into account that only around 25% of the energy crop will be dedicated for biogas production. The rest will be applied in other renewable energy production processes (solid and liquid biofuels).

Table 3. Methane potential originated from energy crops from 5% of the arable land in EU-27 with the cropping yield equal to 10, 20, and 30 tTS/ha

Energy crop yield	10 tTS/ha	20 tTS/ha	30 tTS/ha
Methane potential	25.3 billion m^3CH_4	50.7 billion m^3CH_4	76.0 billion m^3CH_4
	22.8 Mtoe	45.5 Mtoe	68.5 Mtoe

Manure resources

Biogas from anaerobic digestion can be produced from a variety of biomass types. The primary source is manure from animal production, mainly from cattle and pig farms. It also delivers the necessary micro-organisms for biomass biodegradation and is one of the largest single sources of biomass from food/feed industry. In the EU-27 more than 1500 mill tonnes of animal manure is produced every year. When untreated or managed poorly, manure becomes a major source of ground and fresh water pollution, pathogen emission, nutrient leaching, and ammonia release. If handled properly, it turns out to be renewable energy feedstock and an efficient source of nutrients for crop cultivation.

Table 4 depicts the amount of cattle and pig manure produced every year in the European Union.

Table 4. Estimated amounts of animal manure in EU-27 (based on Faostat, 2003)

Country	**Cattle**	**Pigs**	**Cattle**	**Pigs**	**Cattle manure**	**Pig manure**	**Total manure**
	[1000Heads]	[1000Heads]	1000 LU*	1000 LU*	[10^6 tonnes]	[10^6 tonnes]	[10^6 tonnes]
Austria	2051	3125	1310	261	29	6	35
Belgium	2695	6332	1721	529	38	12	49
Bulgaria	672	931	429	78	9	2	11
Cyprus	57	498	36	42	1	1	2
Czech R.	1397	2877	892	240	20	5	25
Denmark	1544	13466	986	1124	22	25	46
Estonia	250	340	160	28	4	1	4
Finland	950	1365	607	114	13	3	16
France	19383	15020	12379	1254	272	28	300
Germany	13035	26858	8324	2242	183	49	232
Greece	600	1000	383	83	8	2	10
Hungary	723	4059	462	339	10	7	18
Ireland	7000	1758	4470	147	98	3	102
Italy	6314	9272	4032	774	89	17	106
Latvia	371	436	237	36	5	1	6
Lithuania	792	1073	506	90	11	2	13
Luxembourg	184	85	118	7	3	0	3
Malta	18	73	11	6	0	0	0
Netherlands	3862	11153	2466	931	54	20	75
Poland	5483	18112	3502	1512	77	33	110
Portugal	1443	2348	922	196	20	4	25
Romania	2812	6589	1796	550	40	12	52
Slovakia	580	1300	370	109	8	2	11
Slovenia	451	534	288	45	6	1	7
Spain	6700	25250	4279	2107	94	46	140
Sweden	1619	1823	1034	152	23	3	26
U.K.	10378	4851	6628	405	146	9	155
EU-27	**91364**	**160530**	**58348**	**13399**	**1284**	**295**	**1578**

*) LU: livestock units

The animal production sector is responsible for 18% of the green house gas emission, measured in CO_2 equivalent and for 37% of the anthropogenic methane, which has 23 times the global warming potential of CO_2. Furthermore, 65% of anthropogenic nitrous oxide and 64% of anthropogenic ammonia emission originates from the same animal production sector (Steinfeld et al., 2006). Table 5 shows the biogas and energy potential of pig and cattle manure in EU-27.

Table 5. Energy potential of pig and cattle manure in EU-27

Total manure [10^6 tonnes]	Biogas [10^6 m^3]	Methane [10^6 m^3]	Potential [PJ]	Potential [Mtoe]
1,578	31,568	20,519	827	18.5

Methane heat of combustion: 40.3 MJ/m^3; 1 Mtoe = 44.8 PJ
Assumed methane content in biogas: 65%

Table 5 reveals that huge amounts of animal manure are produced in Europe. Biogas production through anaerobic fermentation of animal manure is an effective way to re-

duce greenhouse gas emission, especially ammonia and methane from manure storage facilities. The fermentation of manure alone does not result in high biogas yield, but its high buffer capacity and content of diverse elements has a positive impact on the anaerobic digestion process stability. Higher methane yield can be achieved through co-digestion of manure with other substrates such as energy crops. The digested substrate resulted after the process can be further refined and serves as organic fertilizer, rich in nitrogen, phosphorous, potassium and other macro- and micro-nutrients necessary for the growth of the plants. Utilisation of large amounts of animal manure for bioenergy purposes will reduce the nutrient runoffs and diminish the contamination of surface- and ground- water resources by further biotechnological processing and upgrading the liquid and solid biofertilizers for replacement of chemical fertilizers in the European crop farming.
To sum up the biogas production potential, in the year 2020, 45.5 Mtoe of methane from energy crops can be achieved under crop yielding 20 tTS/ha additionally 18.5 Mtoe will be available from cattle and pig manure. The added potential is equal to 64 Mtoe, which would correspond to 71,200 mill. m^3CH_4.

Biogas utilisation applications

Biogas can be utilized in several ways. It can either be applied raw or upgraded, minimum it has to be cooled, drained and dried right after production, and most likely it has to be cleaned for the content of H_2S as well, which in a short time interval will outruine the energy conversion technologies if the H_2S content is above 500 ppm.

There are various ways of biogas utilisation:

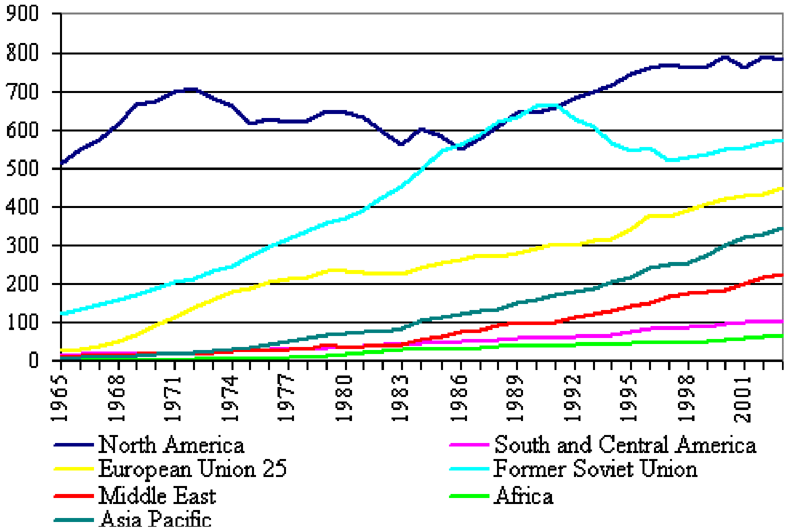
- Production of heat and/or steam
- Electricity production / combined heat and power production (CHP)
- Industrial energy source for heat, steam and/or electricity and cooling
- Vehicle fuel
- Production of Chemicals
- Fuel cells

It can be fuelled to generate heat and/or electricity or applications of combined heat and power (CHP) plants and upgraded to vehicle fuel standards; these will be the most voluminous application routes. One case example of biogas for vehicle fuels is Sweden. The market for biogas as vehicle fuels has been growing rapidly the last 2-3 years. Today there are 12,000 vehicles driving on upgraded biogas/natural gas and the forecast predicts 500 filling station and 70,000 vehicles by 2010 (Persson, 2007).

The most efficient ways of integrating the biogas into the entire European energy sectors are by upgrading the biogas to natural gas quality and integrating it into the natural gas grid. The bottleneck in this area is the economy of each treated m^3-biogas, but various upgrading technologies exists (Persson et al., 2006). In the coming years the economy of scale of upgrading facilities will be met by competition from economy of numbers of installations. It is obvious that the treatment price will be reduced due to the increasing numbers of upgrading facilities installed and also by the economically downscaling of the upgrading facilities fitting to the modular biogas plants existing in countries like Germany and Austria.

Introducing biomethane into the natural gas grids widen up the opportunity to utilize biogas in several ways depending on society needs. This option will be increased due to liberalisation of the energy markets in all European countries, but it requires natural gas quality by advanced treatment technologies. It will be as widely utilisation as for natural gas consumers, from house units for heating or fuel cells to decentralised CHP plants, to industrial costumers and to larger energy consumers as power plants. The coming decade will boost this development, when the installed capacities are increasing rapidly in numbers exemplified by the German biogas growth rate in this decade. The utilisation cannot be centred nearby the biogas production units in the farming areas, the biogas has to be upgraded and transported to the large energy consumption areas where the population concentration is situated.

Figure 1 presents world's natural gas consumption.



Source: UNCTAD based on data from BP Statistical Review of World Energy June 2005

Figure 1: World's natural gas consumption in billion cubic metres, 1965-2004 (International Energy Outlook 2007, Energy Information Administration)

Natural gas consumption has increased in the last 30 years. It accounts for almost one quarter of the world's energy consumption. Much of the world's natural gas is used for industrial sector purposes. It is projected to account for 43% in 2030. The share of Europe in total natural gas consumption was 19.1% in 2000, equals to 459,300 mill. m^3 (International Energy Outlook 2007, Energy Information Administration). The theoretical potential of methane achieved from animal manure and energy crops (only from 5% of the arable land in EU-27) produced through anaerobic digestion process could supply 15.5% of the natural gas consumption in Europe.

Due to the placement of the feedstock for anaerobic digestion process, centralized biogas plants are located in the countryside, whereas the natural gas network is developed in the areas with increased inhabitant density. However, in recent years more interest arises in consumption of CO_2 neutral fuels like biogas. The future of combining upgraded biogas and natural gas will bring combined utilization of those two energy carriers. Biogas produced from energy crops, animal manure, and industrial organic waste can supply nearly half of the European natural gas consumption in the coming decades as stipulated by the calculations in this study.

Gaseous energy sources are more difficult to store and transport than liquid fuels, but this disadvantage is offset by much better combustion properties. The emission of several toxic compounds like nitrogen oxides and reactive hydrocarbon can even be reduced up to 80% compared to petrol and diesel.

Whereas biogas production is the best to utilize manure, not all the energy crops should be converted into biogas. Energy diversity brings stability. Energy crops should be used in different technologies, depending on needs in the particular country/region. “Such a diverse and wide ranging approach to power will bring greater economic security and stability to our environmental and energy future than our current one-size-fits-all approach” (Logan, 2006). Gaseous – liquid and solid biofuels will in diversified combinations with wind, solar and hydro be integrated into the European energy sectors. The bioenergy will cover more than 50% of the renewable energy supply of the fixed goals of the year 2020. But when the renewable energy share is increasing towards 2050 and the fossil fuels faces out there will be needs for advanced hybrid systems, larger energy saving, and energy efficiency programmes.

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The Dutch case - stimulating co-digestion in the Netherlands

By Bert van Asselt –SenterNovem.

SenterNovem a governmental organisation (part of the Dutch Department of Economical Affairs) is involved in the EU-PROBIOGAS project. In this paper an overview of the Dutch developments as a result of the PROBIOGAS project is given.

Introduction

At the start of the PROBIOGAS project co-digestion in the Netherlands was difficult to realise. In this paper a summary of events with respect to the PROBIOGAS project concerning the development of co-digestion in the period 2005-2007 is presented.
Until 2005 digestion of manure in the Netherlands was carried out on small scale. A few farmers and farming institutes were experimenting manure digestion.
In 2004 and 2005 the climate towards co-digestion of manure was changing in the Netherlands. Until 2004, co-digestion in combination with reuse of digestate as fertilizer was not allowed. In June of that year the “positive list” was presented. Agricultural products on this list could be used for co-digestion without excluding the use of the digestate as fertiliser. A financial stimulation of digestion was the subsidiary of green electricity produced from biogas. Since January 2005 for each kWh of produced electricity from digestion of manure a bonus of Euro 0.097 was given by the Dutch government. This bonus was really effective in stimulating co-digestion. During the last two years the number of co-digestion plants was increasing from less than ten in 2005 up to more than 50 at the start of 2007.

Due to this development the question can be made “is stimulation of co-digestion with respect to the PROBIOGAS project still necessary”.
Answering this question is not so easy because the Dutch agricultural sector varies from the north to the south. The southern can be described as a livestock intensive area. Because of these activities and the shortage of fields for reuse the manure this part has a surplus of manure. Digestion or co-digestion of manure will not solve this problem. Combination of digestion with other techniques to reduce the amount of manure could be one of the solutions for the surplus of manure in this part of the Netherlands. The Dutch involvement with the PROBIOGAS project was to deal with the problems of manure in the Dutch livestock intensive areas and to stimulate co-digestion of manure more national wide.

The Dutch case

SenterNovem has a good view on most projects concerning digestion of manure in the Netherlands. SenterNovem was involved in the BRK-project and presented this project as the Dutch case. Near the city of Eindhoven, the region “de Kempen” is an area with intensive agricultural activities (pig, cattle and poultry). It is not possible to reuse the produced manure as organic fertilizer within the area. A surplus of at least 1 million tonnes has to be transported to other regions. In order to reduce the costs of manure disposal, a group of farmers has founded the “Bio-Recycling de Kempen” (BRK). The

BRK has plans to build and operate a plant for the treatment of manure. In the first stage of the plant, slurry of both pig and cattle manure will be mixed and separated in a thin and thick fraction. The thin fraction will be treated in an aerobic purification plant (dephosphation and denitrification). In the next stage the thick fraction will be digested in combination with poultry manure. The capacity of the plant will be about 225,000 tonnes of manure. Since June 2006 several farmers, who produce a total of 200,000 tonnes of manure, have joined the BRK.
The case has been studied by the Danish experts and their main conclusions can be summarized as followed:

Non-technical barriers
Three main reasons for the relatively poor economic performance can be identified as the most important barriers for an enlargement of CAD plants in The Netherlands:

- No waste application is allowed
- Relatively low electricity price
- No market for the heat.

This is in spite of the fact that the Dutch case has excellent preconditions regarding the quality of the biomass supplied to the plant, as it has very high dry matter content, which is an important parameter.

Socio-economic/cost-benefit analysis
The socio-economic analysis looks at the biogas-scheme from the point of view of the society at large. Therefore all consequences of the scheme in any sector of society should in theory be taken into account, - including externalities.

Biogas projects have implications not only for the agricultural sector, but also for the industrial and energy sectors. For the environment, mitigation of greenhouse gas (GHG) emissions and e.g. eutrophication of ground water etc. are important external effects. In this study, efforts have been put into the quantification and monetisation of some of the biogas scheme externalities. Four levels are included in the analysis where the base level does not include any externalities, and the top level includes all quantified and monetised externalities. However, it was not possible to quantify all externalities relevant for the study, such as veterinary aspects.
The socioeconomic analysis does not show the profitability from a business point of view, but it shows the profitability from the society point of view, which means that its results can be used as input and arguments in developing agricultural, energy and environmental strategies.

Socio-economic fuel prices are based on IEA (International Energy Agency) and DEA (Danish Energy Authority) forecasts of future fuel prices.
Electricity purchase is assumed at the socio-economic price that includes costs for transmission and distribution. Sale of electricity, however, is assumed to get the spot market price for electricity. (a result of the decision of the Dutch Government to stop subsiding electricity from sustainable sources).
Diesel and gasoline prices `an consumer` have been assumed.
It is assumed that heat production from the plant can not be marketed.
A quantification and monetization for reduction in N-leakage to ground water have been based on Danish general assumptions. N leakage reduction is 25 % of saved Chemical

N fertiliser, monetised by the value of 3,36 EUR/kg N. It should be emphasised that considerable uncertainty is associated with these assumptions and these may not apply fully in the Dutch case. Specific data for the Dutch case have not been available for the present analysis.

Table 1. Overview results of the analyses of the Dutch case

Costs (levellised annuity)	**Result 0**	**Result 1**	**Result 2**	**Result 3**
			mio.EUR/year	
Invesments:				
Biogas-plant	0.574	0.574	0.574	0.574
Transport materiel	0.000	0.000	0.000	0.000
CHP-plant	0.184	0.184	0.184	0.184
Operation and maintenance:				
Biogas production / biogas plant	0.566	0.566	0.566	0.566
Transport materiel	0.071	0.071	0.071	0.071
Sum:	**1.395**	**1.395**	**1.395**	**1.395**

Benefits (levellised annuity)	**Result 0**	**Result 1**	**Result 2**	**Result 3**
			mio.EUR/year	
Energy production:				
Biogas sale	0.000	0.000	0.000	0.000
Electricity sale	0.785	0.785	0.785	0.785
Heat sale	0.000	0.000	0.000	0.000
Agriculture:				
Storage and handling of liquid manure		-0.037	-0.037	-0.037
Value of improved manurial value (NPK)		0.308	0.308	0.308
Distribution of liquid manure		-1.374	-1.374	-1.374
Transport savings at farms		1.066	1.066	1.066
Veterinary aspects				n.a.
Industry:				
Savings related to organic waste treatment		0.000	0.000	0.000
Environment:				
Value of GHG reduction (CO_2, CH_4, N_2O-reduction)			0.631	0.631
Value of reduced N-eutrophication of ground water:			0.347	0.347
Value of reduced obnoxious smells				0.108
Sum:	**0.785**	**0.747**	**1.725**	**1.833**

	Result 0	**Result 1**	**Result 2**	**Result 3**
			mio.EUR/year	
Difference as annuity: Benefits - costs	**-0.610**	**-0.648**	**0.330**	**0.438**

Conclusions

The significant manure surplus situation in the Noord – Brabant region in The Netherlands form excellent preconditions for CAD plants in this region. Farmers would largely benefit economically as they may achieve considerable cost savings in transport, as the CAD plant is assumed to take over transport costs for surplus manure export to other Dutch regions. Receivers of surplus digested manure benefit from cost savings in fertilizer purchase. Relative high dry matter contents in the manure forms a large potential for biogas production However, the estimates for the economic performance of an hypothetical CAD plant in the region, based on the assumptions made, shows that the system is not economically feasible by the existing preconditions. Electricity price is relatively low in a European context, lack of heat utilization options is a serious disadvantage and organic waste admixture is not allowed. These are the most important non technical barriers that should be removed if CAD plants are to enlarge in The Netherlands.

Socio-economic assessments show that CAD plants, again based on the assumptions made, are indeed attractive for society as multifunctional tools for solution of agricultural, energy and environmental problems in livestock intensive areas in The Netherlands like the Noord – Brabant region

Large Scale Digestion in the Netherlands – After PROBIOGAS

Despite of the results of the Danish analyses realisation large scale co-digestion plants in the Netherlands is still difficult and taking time. The economical feasibility has become worse because of the change in subsiding green electricity since August 2006. This means that all initiatives for co-digestion in the Netherlands are put on hold and waiting for a new system of stimulating sustainable energy (electricity-heat-green gas).

Other developments since 2005 are that due to the possibility of using waste products from agricultural origin as co-products for co-digestion the biogas production per digestion-plant has increased during the last years. The capacity of electricity production has risen from 200 kW to 1 MW per plant. Also the capacity of the digester is increasing (10.000 tonnes in 2005 up to 36.000 tonnes in 2007).

As a result of the PROBIOGAS Project SenterNovem has stimulated co-digestion in the Netherlands by means of organizing presentations, workshops, and preparing fact-sheets of (digestion) projects. In order to shorten the process of legislation SenterNovem introduced a service to bring in knowledge of members of the local government which are experienced in the legislation process of co-digestion. This service has improved the knowledge of co-digestion among the other members of local governments and speed up the process of legislation.

It can be concluded that large scale co-digestion of manure in the Netherlands is still difficult. The increase of the number of small-scale plants during the last two years has shown that co-digestion is an excepted technology in the Netherlands. In combination with manure/digestate treatment techniques for the future there will be a marked in the Netherlands.

Environmental and socio-economic analysis of the setting up of a centralised co-digestion plant in the Walloon Region – Belgium

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Abstract

The PROBIOGAS project supported by the Altener/Intelligent Energy-Europe programme of the European Commission aims to promote the heat and electricity production from biogas in different European countries. The project tends to transfer and apply the results of research and socio-economic methods developed in Denmark to six European regions where centralised co-digestion (CAD) is not well developed. The Walloon Region in Belgium is one of the six participating countries in which selected case studies have been carried out [1]. Part of the project is based on the assessment and quantification of environmental and socio-economic cost and benefits (externalities) linked to the installation of a CAD plant within a specific regional context. Identification of non technical barriers is also an important step for addressing recommendations to local actors and authorities in order to raise some of brakes that hamper biogas development in this region.

Keywords

biogas, centralised co-digestion, green certificates, mitigation of green house gas emissions.

Background and Objectives

Centralised co-digestion (CAD) for the production of electricity and heat is not well developed in Belgium. As there is a real interest for biogas production from agricultural and industrial sectors, there are several non-technical barriers that hinder the development of biogas production in the Walloon Region. Even if the Green Certificates mechanism encourages the production of electricity from renewable sources, this system may not be fully adequate for the production and use of biogas. Because of a lack of knowledge and experience in Belgium it was interesting through PROBIOGAS project to transfer socio-economic methods elaborated in Denmark were the CAD concept is developed for more than 20 years. By adjusting the models to a selected case study the project tends to integrate some externalities linked to CAD plant and to assess costs and benefits for the society as a whole. By increasing awareness about the CAD technology and advantages for different sectors, the PROBIOGAS project may help to remove some brakes and to implement this concept in Belgium.

Belgian case study: the selected area

Despite the livestock intensity (concentrated in some areas) and the hardening of the law concerning the fertilization with organic nitrogen, Wallonia has still a potential for manure spreading as the soil binding rate is lower or equal to 1 for more than 80% of the farms. [2]

The selected area is situated in the Province of Liège in the Walloon part of Belgium. It is characterized by the concentration of cattle breeding (more than 35000 in production) and especially dairy cattle. The localisation of pig and poultry breeding is much more variable.

Most of the land is dedicated to meadows and the main cultivated crops in this area are fodder maize and cereals.

The number of food industries is also important linked to the density of the population that is high around Liège. Food-industries process mainly dairy products, cheese, fruits (syrup and cider), cereals and starch.

Furthermore, farmers of this area and some local authorities are interested in biogas production as 2 biogas projects started in 2005 in the communes of Sprimont (20 farms) and Limbourg (around 20 farms).

For the Belgian case studied in PROBIOGAS it was chosen to merge the data of both projects in order to get sufficient amount of biomass feeding the digester. In total 40 farms have taken part in the study which represents an area of 2208 ha. 41 local food-industries were contacted but response rate was very low (11 out of 41). Because a big part of their by-products is already used for animal feeding and low treatment costs, few industries are currently motivated by treating their wastes by anaerobic digestion.

Technical aspects of the biogas plant

The CAD plant of the Belgian case study will have a treatment capacity of 75000 tonnes a year or approximately 205 tonnes per day. The plant is operated at thermophilic temperatures (around 52 – 55°C) with a 15 days retention time. The plant is equipped with a sanitation tank where effluents are heated to 70°C for one hour. After this step, the biomass is pumped through a heat exchanging system to be introduced into the digester (3100 m³ capacity). After 15 days the digested manure is pumped into a storage tank from where it can be loaded on trucks and driven back to storage at farms. The biogas produced is cleaned by biological process and sent to the CHP (combined heat and power generation) facility.

Table 1: Categories and amount of biomass, biogas yield from different biomass sources

BIOMASS	Type	Amount	DM	DM	VS	CH_4 yield
		t/ year	g/kg	kg/y	kg/y	Nm³/y
Cow manure	slurry	43236	71	3069756	2455805	491161
	deep litter	4651	278	1292978	1034382	155157
Pig manure	slurry	8056	102	821712	657370	197211
Horse manure	deep litter	180	300	54000	43200	8640
Poultry manure	deep litter	2268	550	1247400	997920	349272
Total cattle manure		58391		6485846	5188677	1201441
By-products from industries		16600		1391600	1113280	328824
Total		**74991**		**7877446**	**6301957**	**1530265**

As shown in Table 1, methane (CH_4) production is estimated to 1 530 265 Nm³ a year which is 20 Nm³ per tonne of biomass treated. This relatively low methane yield is due to the low ratio of organic waste and to the low methane potential of the effluents treated. Adding energy crops and other substrates with high dry matter content and high specific methane potential could increase methane yield. Figures 1 shows the contribution of each substrate to the biogas production in the hypothetical Belgian case and reveals a significant increase in CH_4 production if energy crops would be included.

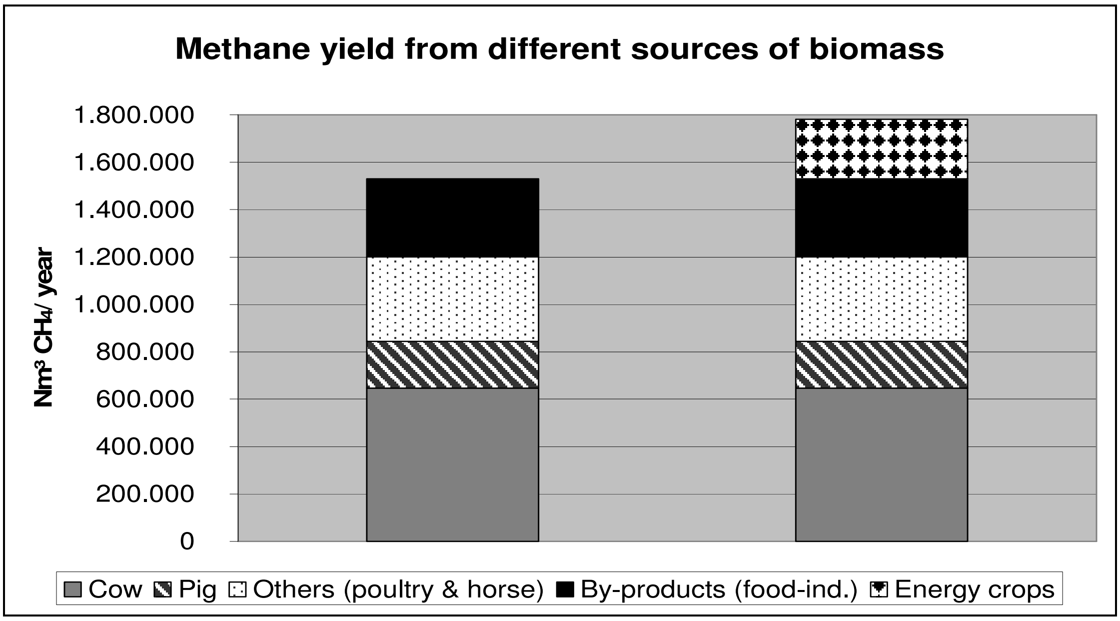

Figure 1: Annual methane production from different types of biomass.

The CHP engine of 800 kW$_e$ converts energy into electricity an heat with shares of 37 % for electricity or 5 500 000 kWh that can be sold to the grid. Heat production amounts to 52% but out of a total of 7 900 000 kWh produced only 2 900 000 kWh can be sold to external users.

Substrates management and agricultural aspects

Through anaerobic digestion (AD) digested slurry has an increased fertilizer value compared to untreated manure. This change is due to the mixture of different animal effluents (pig slurry, cow slurry and solid manure) and to the addition of industrial by-products of various composition. Furthermore, through the process of AD, part of the organic nitrogen is broken down with in final an increase of the mineral nitrogen (ammonium) that is more easily available for the plants. This change can have a significant consequence on fertilization plans. Receiving digested manure, farmers can save money on the purchase of mineral fertilisers.

Calculations have been carried out in order to assess the impact of the CAD system on the fertilisers' application. The demand in nitrogen, phosphorus and potassium are based on the fertilisation recommendations in force in the Walloon Region. The size of the area required to receive manure is calculated on the amount of phosphorus that is allowed applying.

As additional biomass is processed into the digester the volume of digested manure exceeds the volume of manure delivered to the plant. The surplus digestate has to be exported to an 812 ha area. It is assumed that the crops production farms are willing to use digested manure instead of mineral fertilisers. On the other hand, farmers delivering manure to the biogas plant would receive an equal quantity of digested manure that they have provided. Effects on fertiliser purchase and use are detailed in Table 2.

Table 2: Digestate application and savings on fertilisers purchase

Animal production farms	
Total area (ha)	2 208
Digestate to be spread (t/y)	52 791
Savings in mineral fertilisers (EUR/y)	16 890
Crops production farms	
Total area (ha)	812
Digestate to be exported (t/y)	22 200
Savings in mineral fertilisers (EUR/y)	65 569
Total savings in mineral fertilisers (EUR/y)	**82 459**
Savings per ha (EUR)	**27**

There is a great disparity between animal production farms and plant production farms as that highest saving is for arable farms with 81 EUR per ha while saving is only 9 EUR for animal farms. Animal breeders have to spend more buying phosphorus and potassium as P and K contents in digested manure are lower than in untreated manure.

Economic performances of the biogas plant

Treatment capacity and biogas production are the main parameters determining the dimensions of the plant. The assessment of these parameters is based on Danish methods and allows the projection of planning and calculations of the required investments. The economic performance of the plant also depends on preconditions as energy prices and treatment fees that the biogas plant would receive from local industries (Table 3).

The profitability of the biogas plant is calculated on costs and sales of electricity and heat including the income from Green Certificates. The Green certificates (GC) is a transferable certificate issued to producers of green power for a number of kWh generated which is equal to a certain amount of energy divided by the CO_2 saving rate. The CO_2 saving rate is calculated by dividing the quantity of CO_2-saving achieved by the use of electricity and heat from biogas by the CO_2 emissions of a traditional reference system. At present on the Walloon market the value of the GC is around 90 EUR/GC. However, as the green electricity market shows some uncertainty it was chosen for this study to use the minimum value guaranteed by regional authority of 65 EUR per GC. In the present case study it was calculated that 1.24 GC is given for one MWh_e based on biogas. An extra income of 80 EUR/MWh is given for every MWh_e supplied to the grid.

Table 3: Basic preconditions and investment costs in the Belgian case

Treatment capacity (t/d)	200
Biogas yield (Nm³/t)	20
Electricity sale price (EUR/MWh)	25
Heat sale price (EUR/MWh)	30
Value of Green Certificate (EUR/MWh_e)	80
Treatment fee for organic waste (EUR/t)	4,8
Investment for biogas plant (million EUR)	3,9
Investments for CHP facility (million EUR)	0,5
Total Investment costs (million EUR)	**4,4**

The CAD system covers transportation costs for manure and digestate. In this case trucks are hired from an external supplier. The system also meets the costs for storage of digestate. Table 4 shows the average profit of the CAD in 2005 prices. Costs were calculated in Danish 2005 prices and then converted into Belgian 2005 prices by using Comparative Price Levels from Eurostat. An interest of 5,5% is used.

Table 4: Average yearly profit of the CAD of the Belgian case

Item	EUR/y
Transportation costs	-209000
Storage of digestate	-19000
Profitability of the biogas unit	88000
Profit of the CAD system	**-140000**
Profit if biogas production increased by 10%	-90000
Profit if biogas production decreased by 10%	-190000

Even if farmers' savings are taken into account, the system is not quite economic being disadvantaged by low biogas production and the little part of the heat that can be sold. If additional substrates with high methane potential were supplied, the profitability of the plant could be improved.

Socio-economic analysis

The socio-economic analysis differs from the previous economic analysis by looking at the CAD system from the society point of view and by taking into account implications for different sectors. In this part the objective has been to quantify and monetize some externalities that derive from an hypothetical biogas plant given the context of the selected case in Wallonia. Environmental benefits as reduced risks of eutrophication of ground water, mitigations of green house gas (GHG) from the management of manure and organic wastes and substitution of fossil fuels for energy production are important effects that are worth assessing in order to emphasize the advantages of the biogas scheme alternative compared to the "business as usual" situation.

Four different levels were analysed where the base level (R0) does not include any externalities and the highest level (R3) includes all externalities that could be quantified and monetized in the present case. Some externalities have to be assessed using Danish data and others, such as veterinary aspects, could not be quantified because of the lack of specific data available.
The 4 levels that were analysed in the Belgian case can be described as follows:
Result 0: Energy production from biogas plant (no externalities included).
Result 1: Benefits for agriculture and industries (from manure and waste management).
Result 2: Environmental externalities linked to GHG emissions (CO_2, CH_4, N_2O) and reduced nitrogen losses included.
Result 3: Value of obnoxious smells reduction and income via Green Certificates included.

Including a socio-economic value for Green Certificates can be a delicate matter as the GC system may cover different aspects such as GHG reduction. In this analysis it has been assumed that the GC value only relates to benefits for the society in terms of 'security of energy supplies and political stability issues'. In order to prevent double counting or inconstancy, integration of a GC value is taken into account in R3 and is assumed not to include other aspects included in lower levels like the value of mitigation of GHG emissions (R2).

The estimated effects on GHG emissions linked to the CAD alternative is showed in the Table 5. CH_4 and N_2O emissions are expressed in CO_2-equivalent using their respective Global Warming Power (GWP). For a time horizon of 100 years, the GWP of CH_4 is 21 times higher than that of CO_2 and GWP of N_2O is 310 times higher than that of CO_2.[3]

In total 3845 tonnes of CO_2-equivalent can be saved by the deployment of the CAD system. It can be seen that 46% of the total CO_2 emission reduction is due electricity sales assuming biogas would substitute natural gas. Heat sales contribution to CO_2 emission reduction is 24%. The use of digested manure instead of mineral fertilizers contributes to a CO_2 reduction of about 742 tonnes of CO_2-equivalent.
Other reductions derive from biomass management and anaerobic digestion, which lead to lower CH_4 and N_2O emissions. A reduction of about 10 tonnes of CH_4 is achieved by farms meanwhile 6 tonnes of CH_4 are saved through the treatment of industrial by-products. Un-burnt CH_4 from the CHP-motor system has been assumed to be 1% of the total of CH_4 produced. This represents an increase in CH_4 emissions of 11 tonnes. In total the reduction of CH_4 emissions is about 115 tonnes of CO_2-equivalent and contrib-

utes to 3% of the total. The reduction of N_2O emissions achieved by manure and waste treatment amounts to 1,635 tonnes of N_2O or 507 tonnes CO_2-equivalent.

Table 5: Consequences on GHG emissions of the biogas plant in the Belgian case study

		Equivalent CO_2
CO_2	Alternative – Reference (tonne CO_2)	% - split
Gas sales	0	0
Electricity sales	-1762	46
Heat sales	-920	24
NPK substitution	-742	19
Transport fuel	201	-5
CO_2- equivalent	**-3223**	**84**
		Equivalent CO_2
CH_4	Alternative – Reference (tonne CH_4)	% - split
Animal manure	-10	6
Industrial by-products	-6	3
CHP-plant unburnt	11	-6
Total CH_4	-5.5	
CO_2- equivalent	**-115**	**3**
		Equivalent CO_2
N_2O	Alternative – Reference (tonne N_2O)	% - split
Animal manure & other substrates	-1.635	
CO_2- equivalent	**-507**	**13**
GHG in total		
Mitigation in CO_2-equivalent	**-3845 tonne CO_2 equivalent**	**100**
Specific CO_2 reduction	**51 kg CO_2 equivalent/ tonne biomass**	

Consequences of GHG emissions have been monetized and integrated into the calculation of the socio-economic performance of the plant. The socio-economic costs and benefits for the CAD alternative were based on forecasts of fuel and energy prices developed by IEA (International Energy Agency) and DEA (Danish Energy Authority) for the period 2006-2025. Prices for electricity purchase and sales and prices for heat sales are based on Belgian data. The contribution of energy sales to the socio-economic results is showed in Table 6.

Table 6: Annual Energy production and sales, preconditions used in the Belgian case (national price level EUR / MWh)

CH_4 production (Nm^3 /y)			**1530265**
	Electricity	Heat	Green Certificates
Price level (EUR/MWh)	34	30	80
Production (MWh/y)	5500	7900	
Net production sold (MWh/y)	3097	2948	3097
Incomes (million EUR/y)	**0.105**	**0.088**	**0.250**

Because specific data from Belgium were not available the monetization for reduced N-losses to ground water has been calculated on Danish assumptions: N-leakage reduction is 25% of saved N- fertiliser, monetized by the value of 3,36 EUR/kg N. In the Belgian case, the value of reduced N-leakage is equivalent to 61 141 EUR per year. Table 7 presents annual costs and benefits for the CAD alternative according to the 4 levels analysed.

Table 7: Annual socio-economic costs and benefits (4 levels of externalities integration)

Costs as annuity (mill. EUR/y)	**R0**	**R1**	**R2**	**R3**
Invest. biogas plant	0.359	0.359	0.359	0.359
Invest. CHP plant	0.044	0.044	0.044	0.044
Transport	0.027	0.027	0.027	0.027
Operation & maintenance	0.278	0.278	0.278	0.278
Total costs	**0.708**	**0.708**	**0.708**	**0.708**
Benefits as annuity (mill. EUR/y)	**R0**	**R1**	**R2**	**R3**
Electricity sales	0.105	0.105	0.105	0.105
Heat sales	0.088	0.088	0.088	0.088
Incomes from Green Certificates				0.250
Storage/handling/distribution manure		-0.157	-0.157	-0.157
Improved fertiliser value		0.087	0.087	0.087
Transport saving at farms		-0.006	-0.006	-0.006
Savings on by-products treatment		0.062	0.062	0.062
Value of GHG reduction			0.078	0.078
Value of N-losses reduction			0.061	0.061
Value of smells reduction				0.026
Total benefits	**0.194**	**0.180**	**0.319**	**0.594**
Profit (benefits – costs)	**-0.514**	**-0.529**	**-0.390**	**-0.114**

It is seen that even on the highest level including all the estimated externalities (R3), the studied biogas scheme is not economic from the socio-economic point of view and the annual deficit is estimated to 114 000 EUR/y. Nevertheless, if all heat produced on site could be sold substantial incomes could be expected. Additional waste supplies would increase biogas production and thus the profitability. It also should be mentioned that considering the current price of Green Certificate (around 90 EUR/GC) would imply break-even point at the R3.

Non technical barriers and recommendations

The development of CAD in Denmark was favoured by a set of preconditions in terms of legislative incentives as well as economic aspects. Such expansion of biogas production in other regions like in Wallonia is not feasible until non technical barriers specific to the national and regional context could be identified and partly removed.

Legal and administrative procedures are very complex, often progressing slowly. As many steps of CAD projects come under various authorities it is quite long obtaining clear information and authorizations.

The constant supply of substrates of good quality and in large quantity in a minimum radius around the plant is often problematic. Better collaboration between industrial and agricultural sectors could allow the pooling of sufficient amount of substrates ensuring a profitable biogas production. Drawing-up a positive list of authorized substrates could increase the supply of organic matter to raise methane yield. Furthermore, a clear regulation about the authorised substrates with a rationalization of controls may loosen the current *strong restrictions on the use of digestate* by simplifying application and control procedures that are heavy and costly.

In many cases *the lack of heat market* is a brake for the profitability of a biogas unit. Programmes or public subsidies to encourage the installation of district heating may favour an efficient use of the heat. Income from the production and sales of heat produced from a renewable source should not be linked to the green electricity production.

Because of a *poor awareness of the benefits of biomethanation* local people are often afraid of nuisances and can reject some biogas projects. Giving credible information about the impact of biogas plants could prevent such scepticism.

Externalities are not commonly assessed and monetized. Meanwhile, environmental and socio-economic benefits resulting from biogas production should be better integrated by means of financial plans supporting sustainable development.

Conclusion

As many advantages from centralised co-digestion have been demonstrated through research and demonstration programmes in Denmark, PROBIOGAS project has shown that the CAD concept could generate environmental and socio-economic benefits and should develop in other European regions under specific conditions. The present study of an hypothetically CAD plant in the Walloon Region has revealed some limitations as the whole system would not be economic even if all the quantified and monetized externalities that could be assessed within this analysis were integrated. The Belgian case is disadvantaged by the low biogas potential of the substrates and difficulties to pool by-products from external industries. However, the production and use of renewable energy is favoured by the Green Certificates system which can raise substantial income to the biogas plant if additional heat was marketed and sold. The Belgian case study has brought to light advantages for agricultural community in terms of management of effluents and savings on purchase and use of mineral fertilisers. Significant impacts on the mitigation of GHG emission and the security of renewable energy supply via biogas production are important externalities that may encourage decision makers as well as other biogas actors to remove the existing non-technical barriers that hamper CAD development in the Walloon Region.

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Overview of centralized biogas plants projects in France

Will the new economic incentives overcome the non technical barriers?

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Status of biogas in France

In 2005, France used about 8.800 TJ of biogas (209.000 toe) [1]. Most of this biogas is landfill gas (61%). Municipal wastewater treatment plants (WWTP) contribute to 27%, biogas from industry (food, paper, chemicals…) to 11%, and municipal solid waste (MSW) plants to 1%.

In addition, it's estimated that 15.000 TJ of landfill gas are flared, and 17.000 TJ of non-collected landfill gas are emitted to the atmosphere [2].

Biogas production from agricultural sources is negligible. Only 3 farm-scale plants were in operation, and no centralized plant.

The main use of biogas is power production: 460 GWh are produced by gas turbines, steam turbines, gas engines. Most of landfill gas is converted to electricity only. A few numbers of landfills use the heat generated by power plants. On the contrary, most of the biogas generated by municipal and industrial WWTP is converted to heat only, and a few numbers (Paris' main WWTP for example) are equipped with CHP plants. Final heat production is estimated to 2,400 TJ, among which 29% for self-use (digesters heating) and 71% for external use (sludge drying, building heating, steam for industry…).

Biogas production increased at a rate of +10% per year during the last decade (+18% for power production). This trend is going on, and even increasing: more and more landfills are being equipped (+23 MW in 2006, i.e. +33% of installed capacity); new biogas plants are buildt as industrial WWTP.

Three MSW plants are in operation, and twelve new plants are under construction or planned. New AD plants for municipal biowaste were put into service in 2006 and 2007 in Lille and Calais, north of France , and in the French Antilla island of Martinique. The AD plant of Lille will treat 100,000 tonnes of biowaste, source separated. The biogas will be used as a fuel for vehicle: the city of Lille leads the european program "BiogazMax", with the municipalities of Harlem, Rome and Göteborg.

New incentives

The take off of biogas technologies occurred in France at the end of the 90'. Like many other European countries, numbers of landfill gas engines have been set up. Anaerobic digestion for MSW is nowadays considered as a realistic option, while other alternatives as incineration are declining.

But until now, the energy prices were not sufficient to allow the realization of biogas plants in the agricultural sector.

The situation is changing since the publication of new power purchase tariff in July 2006. According to this government decree, the basic price for electricity from biogas will be 90 EUR/MWh for plants under 150 kW_e, and 75 EUR/MWh for plants over 2 MW_e; and linear between 150 kW and 2 MW.

The plants get a "digester bonus" of 20 EUR/MWh if the gas is produced from a digester and not from a landfill.

The plants get another bonus for "energy efficiency" if they use the cogenerated heat. This bonus depends of the efficiency rate: the quantity of energy (electricity and heat) really valorized divided by the quantity of heat value of the biogas. Heat used for the process (digester heating, pasteurization) is considered as valorized. This bonus is nil if the efficiency rate is under 40 %, and reaches 30 EUR/MWh if the rate is over 75 %. It is linear between 40 and 75 %.

That means that the purchase price for a plant of 150 kW_e will be between 110 and 140 EUR/MWh, and between 95 and 125 EUR/MWh for a plant over 2 MW_e.

The "efficiency bonus" is destined to improve the global energy balance. It will strongly encourage the biogas producers to search heat consumers. Biogas dedicated canalizations and district-heating schemes seems to be the best solutions.

This new tariff is certainly a fact of great importance in the biogas policy in France. Numerous projects will become cost-effective in all the domains of biogas and anaerobic digestion. The sensitivity of the operators was increasing from some years ; this tariff is a strong sign addressed by the government in order to encourage the biogas technologies.

Ongoing projects and studies for CAD

Based on the "Danish way" of CAD, several studies are being carried in France.

A first project, LES (Lannilis Energy Service), have been led in Brittany in order to treat surplus of pig manure and biowaste. A denitrification stage was following the anaerobic digestion plant in order to eliminate nitrogen. The project eventually failed.

The GEOTEXIA project (Brittany) is the most advanced CAD project in France. It consists in transforming the nitrogen of manure in a solid fertiliser using the energy of biogas for evaporation and concentration. The plant will cost 16 mill. EUR for 60,000 tonnes of biomass (50% pig manure and 50% food-industry waste) [3].

In Picardie, the FERTI-NRJ project will treat 38,000 tonnes of industrial biowastes and produce 10 GWh el. and 12 GWh heat, for an investment of 5,5 mill. EUR. 89 farmers will invest in the local company, in addition to a private corporation and others partners such the local power company [4].

In West Aveyron (region Midi-Pyrenees), in the framework of the PROBIOGAS program, we studied, with our Danish partners, the feasibility to set up a Centralized biogas plant. This plant could treat 35,000 tonnes of manure and 9,000 tonnes of food industries waste. The plant would be built in the middle of the manure production area and a 12 km long pipe to provide the food industries of Capdenac-Gare should transport the biogas. The power production is estimated to 5,6 GWh and to investment to 5 mill. EUR.

In the area of Jarny (Region Lorraine), the municipality and a group of farmers are looking for a centralized plant for liquid and solid manure and industrial biowaste. The plant would treat 20,000 tonnes of manure, glycerin from a biofuel plant, but no food plant waste. The power capacity will be 750 kW_e and part of the heat will be used in a municipal district heating. The estimated cost is around 5 mill. EUR. A company owned by farmers and local actors will develop the project [5].

In north Deux-Sèvres (Region Poitou-Charentes), the Municipalities Community of Thouarsais and the Regional Council of Poitou Charentes support the TIPER project. Solagro have just achieved the feasibility study. The plant will treat 40,000 tonnes of manure and 12,000 to 15,000 tonnes of food plants waste. A CHP with a capacity of 1,5MW will provide energy to the food plants of the area. The estimated cost is around 8 mill. EUR.

Non technical barriers for CAD in France

Involvement of farmers depends on other alternatives

Due to the new power purchase tariff, there is clearly a competition between individual farm-scale and collective large-scale plants, for the farmers. A farm-scale biogas plant may generate a direct income, like in Germany. In a collective project, the role of the farmers may be limited to exchange raw slurry for digested one.

The fact that anaerobic digestion improves the value of the manure is not necessarily sufficient as a benefit for the farmers. At the contrary, a CAD project induces a change in the manure management, especially with solid manure, which is to a great extend the main form of manure in France.

The collective approach limits the profit or income but also limits the economical risks, compared to individual projects. It may also offer a better valorisation of energy: potential users are not often close to the biogas plant and it’s necessary to transport biogas or heat by canalization . This is economically feasible only for large-scale project.

The benefits of CAD for farmers should be demonstrated with the first CAD plants which will be built in the coming years.

District heating should be developed

As for other renewable sources, the easier way to use heat from CHP is to provide a district heating. In France only 3 % of inhabitations are connected to a district heating and most of them are located in the big cities. District heating should be a priority of local energy policies in order to promote local biomass resources.

A future renewable heat Directive of the European Union, would be helpful for the development of district heating in France.

Dedicated biogas canalizations are a feasible option

One of the interesting ways for energy from biogas is the food–industries. They usually need electricity and heat (steam). It's the case for both the projects in Deux-Sèvres and Aveyron: the natural gas consumption varies between 2 and 15 GWh, which is the magnitude of heat production from the biogas CHP units. But, in Aveyron for example, a 12 km long biogas pipe is needed. It constitutes 20% of the total investment but seems to be profitable with the heat purchase and the electricity tariff.

The regulation concerning biogas canalizations should be renewed and adapted to biogas, and the French "Club Biogas" is actively involved in this task.

Injection into the natural gas grid is allowed but still not possible

Then, injection of biogas into the natural gas grid is perhaps the best way. This option is allowed by the gas act of 2003 and the European Directive, but in practice we are still waiting for the application decrees (in particular there are no norms for trace contaminants in the gas).

A scientific team, on the cover of the AFSSET (French agency for security, health and environment at work) is working on this topic since February 2007.

Several administrative barriers remain

There is still no norm for the solid digestate, unlike for compost from aerobic plants, and this is a barrier for the commercialization and possible sale of solid digestate. Regulation about hazard for biogas plants is not clear. Few researches have been lead, for example about the explosivity of biogas or the agronomic quality of the digestate.

The adaptation of the regulation for biogas and digestate is slowly going on, in parallel to the development of biogas projects, and R&D should be strengthened in order to help policy-makers.

Wanted: the ideal CAD operator

A CAD project affects its surrounding area in many ways: management of organic matter, use of energy, treatment of waste, job creation, environmental benefits… Farmers, municipalities, private companies, may be involved in the project; but no of them are likely to invest some millions of euros in a project where the multiple benefits will be spread between everyone. In France, 3 projects reached the stage of permitting: LES, GEOTEXIA and FERTI-NRJ. The duration between the first studies and the authorization approval was 6 years in all cases, and the development costs reached hundred thousands of euros. Only corporations able to invest such amounts for such long time may support CAD projects. But they have to associate local actors. Multi-party discussions involving private investors, farmers, bankers, local authorities and municipalities, is a great experience.

The potential operators for CAD projects – and their bankers - need a readability of their investments for some years. This means that food industry sector, among other partners of a CAD project, should give some assurance for a sufficient long time.

The lack of private investors seems to be solved, due to the good profitability of CAD plants. But their new interest has to be confirmed in the time.

Conclusion

Three main keys to overcome the non-technical barriers for CAD in France may be emphasized.

The first one depends on policy-makers and regulation. Energy policy may extend the possibility of use for co-generated heat - mainly transportation of raw biogas or injection into the natural gas grid. Specific regulations are required for different aspects, such hazard regulation or organic fertilisers use.

The second key belongs to the farmers. The conditions of their involvement in a CAD project are not yet fully clear. These conditions are closely linked to local conditions and can not be transposed from a country to another or even from a region to another: management of the digestate, fertilising value, perception of benefits from CAD, involvement in the capital share of the CAD plant.

The third key is the private sector: CAD operators, bankers, and food industry. Equilibrium must be reached between risk, profit, and confidence. Eventually, a CAD project is a reasoned gamble for the future.

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The potential for CAD in Ireland

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Background

There are no CAD or large scale co-digestion facilities in Ireland, although some potential projects have completed in depth feasibility studies. In 2002 a report, commissioned by the Environmental Protection Agency (EPA) identified 10 potential sites in Ireland for CAD facilities. The Irish case study, in N. Kilkenny, used for PROBIOGAS was one of the top three identified sites, in that EPA study. This site is in the north-west corner of the South East Region of Ireland. It is therefore a very central location, within the whole of Southern Ireland. The road that joins the two major cities of Ireland, Dublin and Cork, runs through the area. The area is sparsely populated, and mainly agricultural, with small (>250 people) villages.

The case study site is located near a large dairy processing facility that produces large amounts of sludge (16,000 t/y) from its waste water treatment facility. There are several other food processing companies within a 60km radius that would have suitable waste for a CAD. Under the Regional Waste Management Plan there is a need for a second food waste processing facility for the Region of up to 50,000 t/y. There is also a need for a processing facility for the sludge produced by the small rural community sewage works in the county, both needs this project could have met.

The latest Agricultural statistics show that in Kilkenny county there are 1,352,000 t cattle, 149,000 t pig and 700 t poultry manure collected in the year. In North Kilkenny farming is mixed with dairy, tillage and pig production. Most of the cattle farms are dairying, with most of the calves being kept through to be replacements or for beef production. Nearly all farms are family owned farms whether livestock or arable. Some of the farms are in both arable and livestock production, but there are also purely arable production units.

Soils are variable, ranging from dry, free draining to waterlogged ground. Large areas of the county have gravel topsoil and limestone subsoil, and therefore are vulnerable to nutrient and pathogen contamination of groundwater. The River Nore, one of Ireland's largest rivers, and several other waterways run through the area. Most the land (unless waterlogged or the small area of upland in NE and NW) is very fertile alluvial soils and agriculture production is high. There is also quite a high level of Tuberculosis in the cattle herds in the area, which local vets believe is partly caused by untreated slurry spreading.

The Regulatory conditions in Ireland

The Irish Nitrates Regulations 2006 came into force in August 2006, and require farms to have at least 4 months storage capacity and define acceptable spreading times. The Regulations control the amount of available Nitrogen that can be applied and the amount of Phosphate for different crops and the amount of Nitrogen applied in the form of manure (170kg/ha). The draft Regulations of 2005, had indicated that the 170kg/ha limit would apply to N from all organic sources. The change that occurred between 2005-06 meant that organic waste from food processing can continue to be applied to land, with the only limit being crop requirements for available N and the P content and soil P status. This change has removed the driver for food processing companies that have traditionally landspread their waste to find other systems of waste management for the material.

Until December 2006 the Irish Regulations on Animal By-Products, prohibited the spreading of digested products made from feedstock that contained meat, from being spread on farmland. Even today the interpretation of the latest National legislation is still unclear, in relation to category 3 wastes, other than catering waste. The digested products, from a biogas plant licensed to process catering waste, may be spread on farmland, so long as grazing farm animals do not have access, within 3 weeks of spreading (60days for pigs).

CAP reform and the Single Farm Payment, has resulted in uncertainty of the future of farming in Ireland and has caused major changes in landuse. It has also resulted in many farmers (particularly on small farms) becoming part-time farmers or selling up.

Waste Strategy – By 1997 all regions of Ireland had developed Regional Waste Management Plans that outlined what infrastructure was required for each Region to manage its municipal waste arisings. The SE Region advised that biodegradeable waste should be treated by biological means and that 2 of 50,000 t/y facilities should be built. The National target is that 33% of biodegradeable municipal waste should be treated by 2010.

Renewable Energy targets in 2005 were that 13% of electricity consumption should be generated from renewable resources by 2010, nearly all of this was expected to come from wind or existing hydro.

National Climate Change Strategy identifies agriculture as the sector with the highest emissions in Ireland and sets a reduction target of 1.2 mill. t/y from the National herd, 0.06 mill. t/y from changes in manure management and 0.9 mill. t/y from reduced fertiliser use. Large users of energy are required to participate in International Carbon Trading (ICT) and are issued with carbon credits by the EPA.

Waste Licensing – A facility that processes waste and that holds more than 1,000 tonnes of waste on site at any time requires a waste licence from the EPA to operate. This licence places defines the manner of operation, the quality of end products, and places exacting reporting requirements on the facility.

Grid Connections – Ireland has a linear National Grid system that can make it difficult in many areas for the grid to accept embedded generation. Due to large volumes of wind power wishing to come on to the system, there is now a gate system operated whereby any proposed generator >500 kW must apply for connection and wait till the next gate before they receive an estimate. The period between gates is an unknown. A prospective generator must also obtain a licence to build a generating station and a licence to operate.

In 2005 the Support measures that were potentially available were from Sustainable Energy Ireland (SEI) under their RD&D funding for RE. This required the project to have an element of novelty. In 2006 the Government Dept. responsible for energy introduced REFIT a feed-in support scheme for RE, whereby 7.2 EUR-Ct/kW would be paid to the electricity supplier for any electricity they purchased from a biomass generator. And also in 2006 a competitive MOTRII scheme which awarded a small number of excise duty exemptions to biofuels projects, and biogas vehicle fuel would have been eligible. Up to 70% capital grants were available to farmers to install additional storage capacity for manure to meet the Nitrates Regulations.

The combined effect of Irish policy on the design of the case study for this project

The period 2005-08 offered a 'golden opportunity' for the development of a CAD in Ireland, because the CAD would have helped farmers meet the Nitrates Regulations without having to decrease stock numbers or output and most farmers would have qualified for 60% grants for the required farm alterations and long term digestate storage. However, as the grassland farmers, supplying slurry, wanted at least the same amount of nutrients back this meant that the CAD would not be able to process any wastes that contained meat, because of the National ABP rules.

The changes in the Nitrates Regulations between 2005 and 2006, resulted in the dairy only being willing to pay a gate fee to the CAD for taking the WWTP sludge, equivalent to the cost of landspreading the raw material (EUR12.50/tonne).

The price available for the electricity generated provided very low income to the CAD, after allowing for the cost of generating, even with the introduction of REFIT with a price support of 7.2 EUR-Ct/kW. However, as the dairy processing factory is involved in ICT, the carbon credit value of using biogas to replace natural gas to produce heat, could provide additional revenue for the energy, if used to replace natural gas in the factory boilers. SEI offered to provide up to 1 mill. EUR if this approach was taken as using biogas for heat was sufficiently novel in Ireland. However, for the case study to fit into the Danish model, it was necessary to presume the biogas would be used in a CHP, so the SEI grant was not applicable.

The uncertainty about how the Irish ABP rules regarding spreading would be reformed, made it impossible to design the case study to operate as most existing CAD facilities do.

Defining the feedstock and CAD design for the case study

Initially it was proposed that the case study should include two separate digester lines, one that would produce digested products for grassland and one that would process ABP material and plan to utilise the digested products as arable fertiliser. This was agreed in principle by the Dept. of Agriculture. It was proposed to process predominantly food waste and sewage sludge in the ABP line, along with a small amount of slurry. However the Danish model could not accommodate two different digesters in one project. Also there was no data available within the model relating to food waste or sewage sludge. So it was decided to proceed with the case study with one digester that would process 3,200 t/y of FYM, 31,132 t/y of slurry and 18,000 t/y of sludge from the dairy WWTP. The sludge included fats collected from the Diffused Air Flotation unit.

Table 1. *Biomass resources and predicted gas yield*

Biomass	*Amount t/year*	*DM %*	*DM kg/year*	*VS kg/year*	*CH_4 yield Nm^3 CH_4/year*	*Biogas 60% Nm^3 CH_4 /year*
Cattle *slurry*	31,132	7	2,148,108	1,718,486	343,697	572,828
FYM	3,240	20	648,000	518,400	77,760	129,600
Dairy WWTP sludge	18,000	14	2,440,000	1,952,000	691,200	1,152,000
Manure and waste	**52,372**	**10**	**5,236,108**	**4,188,886**	**1,112,657**	**1,854,428**

The digester design was a standard Danish design, consisting of a reception hall with a mixed tank, which fed into a holding tank before passing through heat exchangers and a pasteuriser into the digester. The digester to be operated at 55 ^{0}C. The digestate would be separated (by centrifuge for the model) to remove the coarse fibres (fibre) from the liquid (liquor) fraction. The liquor would then pass to a storage tank from where it is collected to be taken to the receiving farms for long term storage, until it is used. The fibre would be stored on site in a shed where it is composted to fully stabilise it, before it is transported out of the area to a compost product manufacturer.

The gas is collected from the digester and liquor store and is scrubbed before entering a buffer storage tank from where it is fed into a CHP unit to produce electricity and heat.

Operating parameters of the case study

60-70 farms would be involved with the CAD, all within a 7km radius of the CAD site. The manure required to be supplied by about 5,700 LU of cattle. The time that these cattle are housed varies from farm to farm, age and type of stock and from year to year, depending on the weather conditions. Some animals may only be housed for about 50 days, others 160 days. The manure management systems include a) scrapper systems where the slurry is removed from the houses to an outside store regularly during each day; b) slatted tanks where the slurry is stored under the animal houses and c) straw bedded houses (FYM) During winter the slurry from the scrapped systems will be collected within a week of its production and some of the stored slurry in the slatted tanks will also be required. The FYM and the slurry from slatted tanks will be collected in the summer months. Therefore the amount of manure being supplied to the CAD can remain steady all year round.

About 2,300ha of grassland is used to maintain these cattle. Some of the farms have stocking rates in excess of that permitted under the Nitrates regulations. The soil P index of the land ranges from 1-4. These livestock farms also have between them about 70ha of wheat, 185ha of barley, 80ha of sugar beet and 150ha of other arable crops. Due to changes in CAD plant and World Trade arrangements, the use of land in the area may change. However, these farms should provide a large enough landbank to utilise all the liquid products produced by the CAD, even if land use changes. The separated solids will be sold out of the area as a base for horticultural compost production.

Results of the case study

Nutrient Management of the farms in the case study

The case study assessments were made prior to the issue of 2006 Nitrates Regulations. The nutrient analysis of the feedstock and the availability of Nitrogen (taken as early Spring application) is that which was advised by Teagasc, at the time, and actual analysis of the dairy sludge. The calculations assume that no more than 170kg/ha of Total-N from organic material will be spread, and that overall the grassland a maximum of 13kg of P could be spread. In the situation where there is no CAD and wastes are spread untreated, 13,952t/y of the 18,000t/y of sludge would not be able to be used on the farms but would be exported to other farms outside the case study area. With the CAD 3,570t/y of the fibre would need to be sold out of the area.

The effect of processing all the sludge and manure in the CAD increases the Nitrogen availability, and reduces the amount of Nitrogen losses into the environment by 89tpa within the case study area and 36tpa saved outside the area. Correspondingly there would be a saving of 72t/y of Nitrogen fertiliser purchases, overall. Within the case study area there is a saving of over 40,000 EUR pa in artificial fertiliser purchases, or just over 10 EUR/ha. (assuming N/t = 710 EUR and P/t = 1,625 EUR) because some additional P fertiliser will be required if only liquor is used on grassland. The assessment was based on the 2005 Nitrates Regulations, under the current Regulations nearly all the digested products could be utilised in the case study area, which would bring further fertiliser cost savings.

Table 2. Nutrient equation

	quantity t/yr	DM	Total N kg/yr	NH_4 kg/yr	NH_4 %of total N	P kg/yr	K kg/yr	N lost Kg/yr
CAD output whole	49,753	4.7%	178,655	120,349	67.4%	39,919	207,900	
Liquor	45,276	2.2%	128,084	109,456	85.5%	11,173	189,082	18,628
Fibre used local	908	32.0%	10,252	2,208	21.5%	5,828	3,815	8,044
			Total N unaccounted for with digested products					**26,672**
slurry	31,132	6.9%	112,075	28,019	25.0%	18,679	133,868	84,056
manure	3,240	20.0%	14,580	1,944	13.3%	3,240	22,032	12,636
sludge spread	4,048	14.0%	22,669	3,967	17.5%	4,048		18,702
			Total N unaccounted for with untreated products					**115,394**
Sludge exported	13,952	14.0%	82,317	14,405	17.5%	41,856		67,911
Fibre exported	3,570		40,319	8,685		22,918	15,003	31,634
			Total N saved from being lost from exported material					**36,277**

The farmers will have an additional spreading cost to deduct from this fertiliser saving as an additional 13,300t/yr of liquor will be spread compared to manure. The farmers would also require additional storage capacity on farm, it is assumed that the farmers obtain a 60% grant and the balance of the cost of storage is paid by the CAD.

Greenhouse Gas Emissions

The case study assessment has calculated that 71kg of CO_2 equivalent are saved per tonne of biomass treated, even when the CAD is not taking wastes that would otherwise be disposed of to landfill. The CO_2 savings represent 90% of the GHG emissions avoided, whereas with most CAD, other gases make up 50% of emissions avoided. Therefore if the Irish CAD could process ABP waste the GHG emissions avoided would be much higher. The saving in emissions in the case study is calculated by considering the following

a) methane emissions from stored manure and sludge
b) Nitrous oxide emissions reduction achieved by mineralisation of the nitrogen during the digestion process
c) The carbon dioxide emissions avoided by replacing fossil fuel (natural gas) to generate the net output of electricity and heat
d) Allowing for emissions of unburnt methane (1% of fuel) in the CHP exhaust
e) NPK fertiliser substitution
f) Changes in transportation fuel

Table 3. GHG emissions

	Gas type	*Gas as produced t/yr*	*Equivalent in CO_2 t/yr*
Electricity sales	CO_2	-1,856	-1,856
Heat sales	CO_2	-1,217	-1,217
NPK substitution	CO_2	-299	-299
Transport fuel	CO_2	32	32
Manure storage	CH_4	0.3	6.3
Sludge storage	CH_4	-9	-189
CHP unburnt gas	CH_4	13	273
Manure/sludge/fert	N_2O	1.44	-446
			-3,709

For the CO_2 reduction due to NPK substitution the following upstream specific energy and CO_2 contents have been assumed: (38MJ/kg pure N) 9.36kgCO_2/kg pure N, (17MJ/kg pure P) 2.67kgCO_2/kg pure P, and (6MJ/kg pure K) 0.80kgCO_2/kg pure K

Financial Matters

Capital cost of the case study CAD facility in total came to 4,171,000 EUR (Biogas plant= 3,747,000 EUR, CHP=395,000 EUR, centrifuge=157,000 EUR). There is some uncertainty in applying this capital cost as the smallest Danish model was twice the size, and there are significant economies of scale with a larger CAD size.

The net result of operating a CAD of this size and on manure and sludge for which only a low gate fee can be charged (12.50 EUR/t) results in the project having low gas yields and operating at a loss of 225,000 EUR per year after all financing costs are allowed for.

Table 4. Operational costs and revenue

Revenue	**EUR [1000]**	**Costs**	**EUR [1000]**
Electricity sales (4,671 MWh)	275	Electricity purchase for process	-25
Heat sales (4,003 MWh)	92	Maintenance	-127
Sludge treatment fees	230	Sand removal	-2
Fibre (nutrient value EUR 19,000pa)	0	Insurance	-18
		Other costs	-18
		Staff costs	-103
		Premises	-6
		Administration	-15
		Capital financing of biogas plant	-336
		Costs of biogas facility	**- 650**
		Capital financing storage & separation	-62
		Transportation costs	-111
Total Revenue	**597**	**Total Outgoings**	**- 823**

Socio-economic assessment

Not all the socio-economic benefits of CAD have been included in the calculations, as insufficient data is currently available. Those emitted include, security of supply, saved resources, global balance of trade, effect on infrastructure (e.g. roads, grid), SO_x/NO_x, animal and human health benefits, employment and rural development benefits.

Table 5. Socio-economic values

		EUR
Energy	Electricity sale*	136,000
	Heat sale	93,000
Agriculture	Improved manure value	40,000
	Added spreading costs on farms	- 27,000
	Transportation	111,000
Industry	Disposal cost avoided	230,000
Environment	GHG reduction	96,000
	Reduced N eutrophication of groundwater	65,000
	Reduced obnoxious smells	26,000
	Total socio-economic benefit	**548,000**

* The value of electricity sales assumes that biogas produced (net) and used for electricity production substitute natural gas (by energy content). The corresponding CO_2 substitution or reduction is assigned to the electricity production part of the biogas plant output.

Conclusion

A CAD plant in Ireland will not be economically viable, unless at least one or more of the following can be achieved

- A reasonable gate fee can be charged for at least some of the waste processed
- Digested products can be spread to grassland, even if contain meat in the feed-stock
- The value gained for energy generated increases
- The socio-economic benefits are rewarded
- The Nitrates Regulations are applied in a manner that reflects the nitrogen loss avoided rather than the amount of total N applied

CAD facilities in Ireland are unlikely to be able to avail of the economies of scale achieved in other countries, because livestock farming is mostly not intensive and food processing and population is scattered. The road system in rural areas is poor and there are few sites where the heat produced can be utilised. However, even with a small CAD facility the socio-economic benefits are significant at 230,000 EUR/yr (this value would increase if the CAD processed material that would otherwise go to landfill). The socio-economic benefits of the case study are

- GHG emission savings of 3,700 (71kg CO_2 equivalent/tonne biomass treated)
- 72 t/yr of nitrogen fertiliser saved (1.4kg/tonne biomass treated)
- A saving in production costs for farmers of 10 EUR/ha
- 18t/yr of nitrogen leaching to groundwater saved (1,25 EUR/tonne biomass treated)
- All obnoxious smells from spreading

Unpredictable changes in legislation and a lack of long term vision and planning, make it very difficult to develop a CAD facility which takes 3-5 years to develop.

Unless Ireland adopts spreading rules, similar to other EU countries, it is unlikely any CAD facilities will be built in Ireland.

Table 6. Assumptions used for calculations

Carbon value	20 EUR/t CO_2
Required storage capacity solid manure in months, reference	9
Required storage capacity liquid manure in months, reference	4
Required storage capacity fibre fraction in months, case study	2
Required storage capacity liquid manure in months in case study	6
Price, electricity sold, EUR per kWh	0,072
Price, electricity, own production for process purposes, EUR per kWh	0,072
Price, heat sold, EUR per MWh	20
Capacity of trucks in use, tones, solid/liquid manure/liquor	20/30
Average speed, transport vehicles local roads, km/h	30
Average speed, transport vehicles long distance transport, km/h	60
Liquid manure transportation to and from the CAD EUR	1,70
Solid manure transportation to the CAD EUR	2,70
Long distance transportation EUR	4,80
Average distance from farm storage to spreadland , km	0,75
Average distance from farm to CAD, km	4
Average distance, long distance transport, sludge/fibre, km	10/50
Interest rate	5.5%
Avoided obnoxious smell (cost difference for soil injection) EUR/t	0,50
Reduced N leakage to groundwater (=25% saved N fertiliser) EUR/kg	3.36

Barriers and incentives of centralized co-digestion in Spain. Case study of Pla d'Urgell, Catalonia

By J. Mata-Álvarez, K. Hjort-Gregersen, H. B. Møller, S.G. Sommer, T. Birkmose, and L. Henrik Nielsen

Introduction

Spain is the second largest pig meta producer, behind Germany in the European Union, with 3% of the world output and 16% of the EU production (Lence, 2005). According to the Catalonian government, 28% of the Spanish pig production takes place in Catalonia, where more than 10,000,000 m^3 /yr of animal slurry are produced.

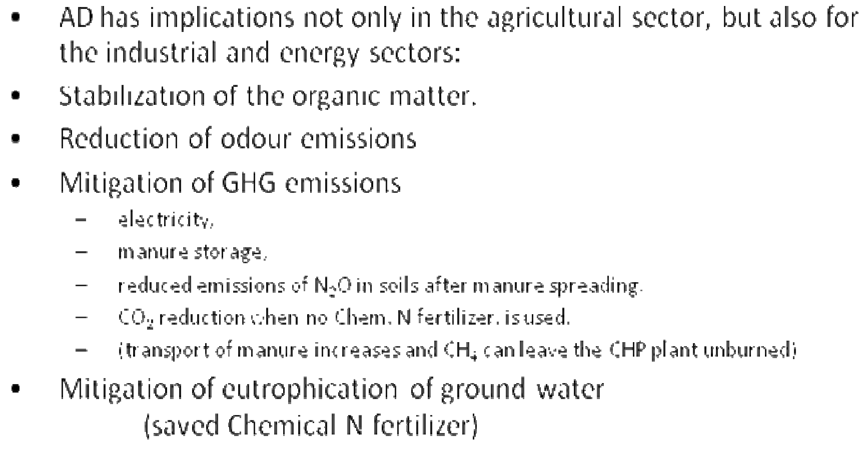
Pig producers in the areas with the heaviest concentration of production facilities in Catalonia are forming cooperatives to build waste-disposal plants that eventually transform slurry into electricity and fertilizer.

Main problem of pig manure is the high ammonium concentration of slurries, linked to the intensive exploitation areas, which results in a very important surplus of nitrogen in certain regions. According to Mata-Álvarez (2003), the Netherlands with 200 kgN/ha/y is heading the European mean surpluses of N. Spain has an average value of 21, but Catalonia has a large concentration of approx. 74 kgN/ha/yr. This makes an overall excess of 30,000 t N/year, but in some areas, as Pla d'Urgell, the surplus rises to 500 kg N/ha/y, that is, more than double of the allowed value in accordance with the 91/676/CEE Nitrogen Directive.

These values can be used as a guideline to select the right location of centralized treatment, and in fact, Pla d'Urgell has been chosen a case study of PROBIOGAS project. Another area in Catalonia with a similar surplus of N is "Les Garrigues", where already two centralised digestion plants for pig manure exists.

AD centralised plants has a number of advantages summarised in Table 1.

Table 1. Some advantages of AD centralised plants for pig manure



- AD has implications not only in the agricultural sector, but also for the industrial and energy sectors:
- Stabilization of the organic matter.
- Reduction of odour emissions
- Mitigation of GHG emissions
  - electricity,
  - manure storage,
  - reduced emissions of N_2O in soils after manure spreading.
  - CO_2 reduction when no Chem. N fertilizer. is used.
  - (transport of manure increases and CH_4 can leave the CHP plant unburned)
- Mitigation of eutrophication of ground water
  (saved Chemical N fertilizer)

Location of the study-case

The study-case is an AD centralised plant to be installed in a farm located in Vilasana, which is a municipality in the region of Pla d'Urgell, within the province of Lleida (see Figure 1). This is a rather dry region with a low density of inhabitants dedicated to agriculture and farming.

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This region, Pla d'Urgell has around 320,000 pigs which represent around 4% of the total livestock units in Catalonia. They are distributed in 250 farms. Vilasana, one of the municipalities, with an area of 19,3 km^2 and 540 inhabitants, has 15 farms and 26,000 pig livestock units, which represents a high concentration. The largest farm is the one called Porgaporgs, which has been selected as the hypothetical centre to build up a centralised biogas plant. As a whole this farm has around 7000 pigs, distributed as shown in Table 2. In the nearby two other relatively large farms are located, named Vehi1 and Vehi2.

Data for these two additional plants are also presented in Table 2. In addition other smaller farms could join the project and as commented below, some agro-industrial wastes are available to be co-digested in this centralised AD plant.

Table 2. Basic data of the main farms contributing to the centralised co-digestion plant

	Central Farm (Porgaporcs)	Farm Vehi1	Farm Vehi2
Fattening pigs (produced/year)	4000	1700	1000
Sows (stable places)	600	200	100
Young pigs (less 20kg) (produced/year)	2400	1000	500

Taking into account the number of livestock units, the total amount of manure produced in these 3 farms can be estimated to be around 57,200 t/yr. Considering all the pig farms in the area, this amount is increased until 129,500 t/yr, whereas cattle manure amounts approximately 30,000 t/yr, poultry around 4,700, and other organic waste coming from food industry, almost 4,000 t/yr. All these wastes and manures gives a total yearly amount of nearly 170,000 t/y. Presently, these amounts of waste are either spread in due time (normally once per month, except in winter) in the fields or sent to a composting plant (solid fraction or industry waste) where they are processed and used later in the fields. This composting process cost to industrial producers can be estimated to be around 25 EUR per tonne.

It seems that a centralised co-digestion plant could help in reducing the cost treatment for industrial wastes, potentially increase the fertiliser value of manures and to decrease the GHG emissions due to manure storage. In addition biogas would be produced which could be transformed into electricity and heat. Unfortunately, heat could not be used for district or industrial heating, because of the distances and the climate conditions. Another added benefit of centralised co-digestion would be the reduction of odours as pointed out in Table 1.

Centralised co-digestion plant

The Danish expert group took basic data shown in the above section and some other concerning temperatures, seasonality, etc. and proceeded to design the centralised co-digestion plant. As the amounts of biomasses were fairly low, they consider comprising other piggery wastes available in the region. As a summary Table 3, shows all the sources of biomass considered for co-digestion.

Table 3. Total yearly amount of biomass resources considered in the project

Type of biomass resources	**Tonnes**
Cattle manure	29,690
Pig manure	129,500
Poultry manure	4,700
Organic waste	3,850
Total	167,740 (460 t/d)

From this biomass approx 4.4 mil m^3 methane production is estimated in two digesters of 3,500 m^3. In the CHP plant this energy is converted into electricity and heat. Electricity which may amount to approx. 16,000 MWh is sold to the grid; heat can not be utilized, apart from some heat used for process heating

The plant is operated at thermophillic temperatures, which means 52-55 ºC and 15 days retention time. The plant is equipped with 70 ºC pre-sanitation step, heat exchanging, biogas cleaning facilities, odour control system, storage facility for biogas and CHP plant for heat and power production.

Investment costs have been estimated to be as follows (in thousand Euros):

CAD Biogas plant	5,300
CHP facility	1,250

In the following section an analysis of costs benefits, based on several factors (Mata-Álvarez et al. 2006), is performed. A number of externalities relevant for the socio-economic analysis have not been included due to lack of data.

Annual costs and benefits

An overview of the annual costs and benefits entering the socio-economic calculation is given in Table 4. The analysis has been carried out in 4 levels termed Result 0, Result 1, Result 2, and Result 3, characterised by:

- Result 0: Energy production (e.g. biogas, heat and electricity) from biogas plants. Externalities not included.
- Result 1: Benefits for agriculture and industry are added to the analysis.
- Result 2: Environmental externalities concerning GHG emission (CO_2, CH_4, N_2O) is added, if quantified.
- Result 3: A monetised value of reduction in obnoxious smells is furthermore added.

Further income elements are added to the analysis when going from the Result 0 level to Result 3, as shown explicitly in the table. All quantified and monetized consequences available for the present analysis are included in the overall socio-economic result termed Result 3. The annual costs (levelised annuity) for investments, reinvestments, and operation and maintenance of the CAD and CHP facility has been calculated using a socio-economic interest rate of 6.0% p.a. This annual cost amounts to 1,076,000 EUR/year as seen in Table 4. The annual income elements for society or the benefits achieved are composed of benefits achieved in different sectors of society. In Table 4 these are grouped into net environmental benefits, benefits in industry, and in agricultural, and (net) energy production benefits.

Table 4 Annual socio-economic costs and benefits for the CAD alternative

Socio-economic results **Biogas plant:**
Annual costs and benefits **Pla d'Urgell, Catalonia, Spain. Base Case**

Costs (levellised annuity)	**Result 0**	**Result 1**	**Result 2**	**Result 3**
		mio.EUR/year		
Invesments:				
Biogas-plant	0.493	0.493	0.493	0.493
Transport materiel	0.000	0.000	0.000	0.000
CHP-plant	0.109	0.109	0.109	0.109
Operation and maintenance:				
Biogas production / biogas plant	0.413	0.413	0.413	0.413
Transport materiel	0.061	0.061	0.061	0.061
Sum:	**1.076**	**1.076**	**1.076**	**1.076**

Benefits (levellised annuity)	**Result 0**	**Result 1**	**Result 2**	**Result 3**
		mio.EUR/year		
Energy production:				
Biogas sale	0.000	0.000	0.000	0.000
Electricity sale	0.479	0.479	0.479	0.479
Heat sale	0.000	0.000	0.000	0.000
Agriculture:				
Storage and handling of liquid manure		0.000	0.000	0.000
Value of improved manurial value (NPK)		0.160	0.160	0.160
Distribution of liquid manure		-0.456	-0.456	-0.456
Transport savings at farms		0.000	0.000	0.000
Veterinary aspects				n.a.
Industry:				
Savings related to organic waste treatment		0.104	0.104	0.104
Environment:				
Value of GHG reduction (CO_2, CH_4, N_2O-reduction)			0.399	0.399
Value of reduced N-eutrophication of ground water:			0.166	0.166
Value of reduced obnoxious smells				0.083
Sum:	**0.479**	**0.287**	**0.852**	**0.936**

	Result 0	**Result 1**	**Result 2**	**Result 3**
		mio.EUR/year		
Difference as annuity: Benefits - costs	**-0.596**	**-0.789**	**-0.223**	**-0.140**

When the sum of the monetised annual benefits exceeds the costs the proposed scheme is of course attractive for society based on the assumptions made. From Table 4 it is seen from the negative net benefit Result 2 value, that the CAD scheme in question is not attractive for the society and that a socio-economic annual deficit of about 223,000 EUR/yr could be expected. Including Result 3 assumptions and the monetised value of the externality 'reduced obnoxious smells', the estimated socio-economic deficit decreases to about 140,000 EUR/yr.

As a summary, with respect to the availability and quality of manure and waste, preconditions are relatively favourable for this case. But low electricity prices and the lack of heat marketing options form serious barriers for economic operation. Calculations show, that the biogas plant itself would be economic, but it is not able as it seems also to cover transport costs. This situation could be altered by supplying more organic waste, or finding a market for heat to improve energy efficiency and economic performance.

Conclusions

The main conclusions of the socio-economic analysis of the proposed CAD-plant project for Pla d'Urgell, Catalonia, Spain (Base Case) are:

- Based on Result 0 assumptions the plant is not attractive. Thus, the socio-economic value of energy production alone can not justify the deployment of the proposed biogas plant project.
- Based on Result 1 assumptions, where net agricultural benefits and benefits for industry concerning treatment of organic waste are included in the analysis, the proposed project remains unattractive for society at large.
- Based on Result 2 assumptions where the calculated environmental implications (net benefits) on Green House Gas emissions (CO_2, CH_4, and N_2O and N-eutrophication of ground water furthermore are taken into account, the annual socio-economic deficit is calculated as 223,000 EUR/yr.
- Including furthermore the estimated externalities related to reduction of obnoxious smells (Results 3), the annual socio-economic deficit is reduced to about 140,000 EUR/yr for the biogas plant in the configuration considered.

These results clearly show that the economy is, of course, a barrier. But what about the incentives? Social benefits are, in a way, an incentive, but, right now, from the economical point of view the only incentive for farmers is the sale of electricity. With the present situation and at the present price this is not a real incentive. As the only way of being remunerated is the electricity sales, the creation of green certificates to increase the electricity fee up to a 14-16 EUR/MWh. This has been pointed out in a recent meeting with TGN in Barcelona, in the framework of the PROBIOGAS project. Other incentives such as the sale of heating power or finding additional environmental benefits, are right in theory but too far from the practice for farmers. Additionally, it should be taken into account that the CAD is not going to solve the problem of the manure excess. Thus farmers should find a real profit to invest in this kind of projects. However, the estimation carried out here shows that the feasibility is not so far, if a small help from the administration, establishing better fees for the electricity sales.

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Biogas in Greece: Current situation and perspectives

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Introduction

Biogas is being promoted in the electricity market to reduce both dependence on imports and exposure to international energy markets, as well as to reduce GHG emissions in the atmosphere. The electricity market in Greece, from 1950 to 1994, was dominated by the Public Power Corporation (PPC), which was the only company producing, transmitting and distributing electrical energy in Greece. The PPC generation system consists of the interconnected mainland system (some nearby islands are also connected there), the systems of Crete, Rhodes, and the independent systems of the remaining islands. From 1994 it was allowed to auto-producers and independent producers to generate electrical energy from renewable energy sources while from 2001 the deregulation of the electrical energy market was established.

Even though the government favours the use of natural gas in power generation, low-quality lignite domestically extracted still accounts for 30.72% of Greece's total energy needs in 2005 and contributes 55.9% to the national electricity production (Ministry of Development, 2005).

Greece successfully introduced natural gas into its energy mix in 1996. In 2005, natural gas imported from Russia and Algeria in the form of LNG was estimated to account for 6.6% of gross energy consumption and gas consumption is growing fast. It has already a good footing in power production and has replaced some oil use in the industrial sector. In 2005, natural gas contributed 12.9% to the electricity production in Greece. In the future, most growth in gas demand is expected to come in power generation and in the residential and services sectors. The current gas infrastructure is sufficient to meet demand for several years.

Renewable energy sources –wind energy, small hydro, biomass and photovoltaics-contributed 3.1% to the Greek electricity production in 2005. Biogas accounted for 3.2% of RES contribution, with an installed capacity of about 24 MW, coming from the exploitation biogas energy of landfill generated in Sanitary Landfills (SL) and biogas generated in Municipal Wastewater Treatment Plants (MWTP) in the region of Attiki.

Biogas current situation and potential resources

During the 1980's a few efforts for biogas energy exploitation were attempted in Greece, the feedstock being mainly animal wastes and wastes from food processing industries. Some of the efforts were demonstration projects, which were finally abandoned because of a number of reasons, the most important being the lack of proper legislation, financial incentives and lack of public awareness. Nowadays, the situation has changed and there are a number of legislative measures and financial instruments available to support biogas investments in Greece and a series of information campaigns to initiate public awareness and stakeholders' involvement in biogas.

The installed power capacity produced from biogas in 2005 was 24 MW, which corresponded to primary biogas production of 1,507.2 TJ. For 2006 the respective figures were 36.39 MW and 2,905.80 TJ. The biofuel is coming from the exploitation of biogas generated in Sanitary Landfills (SL) (2,268.84 TJ in 2006) and biogas generated in Municipal Wastewater Treatment Plants (MWTP) (636.97 TJ) mainly in the region of Attiki (Table 1). As noted in Table 1, only the large-scale anaerobic digestion (AD) plants of Psyttalia and A. Liosia produce power and heat, while the rest produce only power.
So far a number of additional requests for permits have been submitted to the Regulatory Authority for Energy (RAE) and approved for about 11 MW of additional electricity generation in the coming years. This figure is relatively low compared to the potential energy generation from SL and MWTP.

Table 1: Anaerobic plants in Greece

Plant	Feed-stock	Amount (m^3/day)	Gas production (Nm^3/day)	Primary production of biogas (TJ/yr)	Installed capacity (MW)	Produced electricity (MWh_e)	Produced heat (MWh_{th})	Produced heat (TJ/yr)
MWTP of Chania	Sewage sludge	17,000	1,085	9.12	0.21	130		2.2
MWTP of Heraklion	Sewage sludge	23,000	3,200	26.90	0,19	465		4.3
MWTP of Volos	Sewage sludge	27,000	1,500	12.61	0,35	240		4.12
MWTP of Psyttalia	Sewage sludge	760,000	70,000	588.34	7,14	28,000	40,300	145.22
SL of A.Liosia	Landfill gas		164,000	1,107.41	13,8	264,000	0	0
SL of A.Liosia (Expansion)	Landfill gas		112,000	756.28	9,7	190,000	84,500	304.49
SL of Taga-rades	Landfill gas		60,000	405.15	5,0	95,600	0	0
TOTAL			**411,785**	**2,905.80**	**36,39**	**578,435**	**124,800**	**460.32**

Regarding the potential resources for biogas production in Greece, sheep, goats and lamps breeding represents the highest percentage of livestock but this is mainly shepherded and thus the produced manure is spread on the grazing land (Bookis, I. 1997). Currently in Greece there are about 33,000 calf-breeding farms with 723,000 breeding animal heads, 36,500 pig-breeding farms with 140,600 sows, 2,500 olive oil mills, 25 secondary olive residues treatment facilities and a considerable number of food industries.

Table 2: Biomass potential (of the main organic wastes) in Greece

Category	Units *	Capacity *	Organic wastes (t/yr)	Installed capacity (MW)
Cattle	32.875	727,040 cattle	14,540,800	278
Sows	36.593	140,645 sows	2,268,220	37
Slaughterhouses	101	77,242 t/yr (Cat 2) 127,690 t/yr (Cat 3)	204,932	28
Milk factories (milk processing for cheese production)	548	160,362.4 t/yr goat milk 447,705.2 t/yr sheep milk	425,647	7.21
Total			**17,439,599**	**350.21**

* Source: Ministry of Agricultural Development and Food

The potential users for biogas production through AD would be focused on intensive livestock, such as medium scale livestock units (Table 2).

According to Table 2 and based on a conservative scenario, about 17,400,000 tonnes of main organic wastes are annually produced in Greece. It is estimated that the AD of manure and organic wastes from the slaughter houses and milk factories could feed CHP plants of total installed capacity of 350 MW. A mean annual electricity production equal to 1.121.389 MWh_e/yr (38,5% efficiency 5% maintenance) and 1.349.000 MWh_{th}/yr or 4861 TJ/yr (44% efficiency) of thermal energy.

Following the previously mentioned data, eight centralised anaerobic digestion (CAD) plants, of 5-20 MW installed capacity, could be constructed in Greece, in areas of high organic waste potential that is associated with high environmental risks created from their uncontrolled disposition. An advantage noted is their close proximity (all proposed plants are in a radius of 20-25 km) that lowers the transportation costs of the organic wastes to the centralised AD plants.

Legal framework and support measures

The following legislative framework on RES, including biogas, is currently in place:

- **Law 2244/94**, regarding revisions on the electricity production code from RES, and the implementing Ministerial Decision 8295/95, which broke new ground for the promotion of RES in Greece. This law remained in force only until the end of 2000, when it was replaced by the law 2773/99 for which it still acts as reference.
- **Law 2773/99** regarding the liberalisation of the electricity market in Greece. Key features include:
  a) priority to the electricity produced from RES to cover the demand of electricity
  b) a ten year contract to the producers of electricity from RES at a price which will be 90% of the existing medium voltage tariff, at maximum, for the energy produced.
- **Development law 2601/98**, replacing 1892/90, which was the main funding tool of RES applications.
- **Law 2941/2001** regarding the simplification of procedures for establishing companies, licensing Renewable Energy Sources plants, etc.
- **Law 3017/2002** related to the ratification of the Kyoto Protocol to the Framework-convention on climate change",

The new developments in the legislative framework are the following:

- **Law 3299/2004** on promotion of investment. Subsidies vary from 40- 55% according to region, and the type of the enterprise (in case of SMEs and specific regions they can reach up to 55%) (www.elke.gr is the official site of the Hellenic Centre for Investment). Support on capital cost (up to 40%) for biodiesel plants was included in the 3rd Community Support Framework (Energy), which ended last year. The 4th Framework is under development and respective provisions are expected to be put forth.

- The Biofuels directive 2003/30 has been adopted by the Greek government late 2005, as **law 3423/2005**. According to this, biodiesel will be the main biofuel for the Greek transport sector with bioethanol playing a less important role until 2008. The amount of biodiesel required to satisfy the indicative target of 2% (on a lower calorific basis) for the year 2006 has been estimated to be circa 80.000 tonnes while the amount to satisfy the indicative target of 5.75% for the year 2010 has been estimated to be about 148.000 tonnes.
- The Directive 2001/77 on electricity from RES has been adopted by the Greek government in June 2005, as **Law 3468/06**. According to this, a target of 20.1% RES contribution incl. large-scale hydro on electricity production in 2010 has been set. The main scope of this new law is to simplify the permitting system for the RES investments in Greece (i.e. licensing procedures). A point of strong interest is the new electricity feed-in-tariffs system, applicable for the sales of RES-produced electricity to the grid. Electricity produced by biomass is set at 73 EUR/MWh.
- Join **Ministerial Decrees** 54409/2623(27/12/2004) ruling the Emissions Trading schemes
- Specific Spatial Planning Framework and Sustainable Development for RES. According to this plan, for biomass and biogas exploitation, favourable areas are considered these located in near proximity to agricultural lands where biomass is produced, waste treatment plants, food industries, animal breading farms. Minimum distances from the nearby land uses are set. The plan is under public consultation.

The financial measures set for RES applications, including biogas are the following:

- The Operational Programme of Energy (OPE) (1994-2000) of the 2nd Community Support Framework (CSF) is the most important financing instrument for RES promotion in Greece. Currently, the funding mechanisms of the Operational Programme of Competitiveness (OPC) of the 3rd CSF, initiated in 2000-2006 by the Ministry of Development, gave a further impulse to RES projects, with a total budget of about 777.6 mill. EUR (public funding of about 268.4 mill. EUR). Biomass share was 60.7 mill. EUR, out of which the 31.4 mill. EUR were spent on biogas projects.
- A provision has been applied to give the 3% of the electricity sales in favour of the municipalities, in order to curtail any public opposition in areas with high RES potential. A significant budget has been earmarked for the upgrading of the electricity network in areas of high wind or biomass potential.

It is expected that with the forthcoming 4th CSF private investors will take advantage of the funding mechanisms and the upgrading of the network and will invest.

Risks and barriers

There are a number of key risks and barriers that can threaten investment in biogas projects and thus prevent more rapid uptake of desirable technologies. Barriers associated with investment opportunities, on a macro-economic level, were categorised according to distinct but interrelated topics and include:

- Cognitive barriers, which relate the low level of awareness and understanding of the financing schemes and risk management infrastructures
- Political barriers, associated with regulatory and policy issues (lack of gate fees, lack of regulatory price for heat)

- The small-scale of projects,
- Resource availability and supply risk, either in terms of assessing the resource or contracting the supply (reduction of gas quantity and quality due to changes in organic feedstock)
- High investment costs
- Planning opposition associated with odour problems

Biogas projects suffer significantly from resource supply risk and small scale. One issue that comes up repeatedly when seeking finance for biogas and cogeneration projects is security of supply and fuel price volatility.

Large plants owners are not properly aware of the technologies for manure treatment and potential biogas-to-energy applications, while, on the other hand, small plants cannot in general effectively combine forces with other producers to form clusters of enterprises and create viable biogas plants.

The few potential investors that are fully aware of all the benefits of biogas exploitation mentioned are discouraged to proceed to similar investment due to the high investment cost and the low public subsidy (grant). The financial return for an AD plant is insufficient to repay the investment outlay, because financial analyses do not include the socio-economic costs and environmental benefits (external costs).

Although new laws and ministerial decrees have been adopted, which improve the institutional and the legal framework for such investments, these investments are resource-limited, i.e. the “polluter pays principle” is not applied practically, which would greatly improve operational costs by imposing gate fees to polluters and help remove uncertainties for the power plant owners.

Liberalisation of the energy market, that would initiate investments, is not fully implemented in Greece and PPC still retains the leading position in power generation and supply.

Perspectives and Success conditions

A realistic scenario was produced (Ministry of Development, 2005) to assess the demand for installed power capacity from RES that is needed to reach the target of 20.1% contribution of RES in the internal electricity market. According to this scenario, the requirements in installed capacity by 2010 from biomass are 103 MW, which corresponds to 0.81 TWh and accounts for 1.19% of the RES share (Table 3). The scenario was based on the assumption that the share of various RES types will not vary significantly in the next four years; thus the biomass-produced electricity will derive mainly from biogas. This assumption is considered as realistic given that rapid technological evolution that would lead to significant changes in the economic viability of the various technologies is not expected.

Table 3. RES installation requirements to meet the 2010 target

	Requirements in installed capacity by 2010, in MW	**Energy generated in 2010 in TWh**	**Percentage share of every renewable energy source in 2010**
Wind parks	3,372	7.09	10.42
Small-scale hydro	364	1.09	1.60
Large-scale hydro	3,325	4.58	6.74
Biomass	103	0.81	1.19
Geothermal	12	0.09	0.13
Photovoltaics	18	0.02	0.03
Total	**7,193**	**13.67**	**20.10**

Referring to the success conditions, some corrective actions that may be undertaken to improve and speed up the current licensing process of RES, including biogas, are outlined below:

- Strict adherence to the deadlines set for the various RES applications which are rarely respected by the public electricity company, by the relevant departments of the Ministry of Development and the Ministry of Environment, Civil Planning and Public Works, by the regional and prefecture authorities, etc.
- Substantial reduction in the number of public- sector entities (departments, committees, agencies, etc.) required to approve environmental licensing of RES installations, so as to initiate investments.
- Detailed examination of the possibility to incorporate all RES –licensing procedures into a ‘one-stop shop’ mechanism, under the supervision of the Ministry of Development.
- Creation of national clusters consisted of representatives from SMEs, technology suppliers, specialised contractors, equipment manufactures, financing providers, policy makers (Ministries, Local Authorities) etc. that would assure constant and efficient linking between different policies – on energy, environment, etc – and marketing activities on biogas deployment. The aim of such clusters would be to determine synergies, dependencies and interactions between the involved key players for each stage of a biogas plant life cycle and find out which productive systems can be derived.
- Increase of the percentage of the public funding on the investment capital costs from the 40% that is now to 50%, mainly for the advanced bioconversion technologies.
- Improvement of the biogas market conditions (increases of demand and thus increases of the selling price of the energy products). This could be achieved through the increase of the amount of the de-taxed biofuels and the price of the biogas-produced electricity to the grid (73 EUR/MWh set at present to the 150 EUR/MWh).

Conclusions

Biogas currently exploited is mainly in the form of landfill gas and sewage sludge generated gas. However, Greece has a high organic waste potential that currently is not exploited. Eight CAD plants could be constructed, with a total installed capacity of 350 MW, in areas of high organic waste potential.

The legislative framework and financing mechanisms are constantly being improved, but the still high investment costs coupled with the lack of public awareness on biogas production advantages, the lack of implementation of a 'gate-fee', as well as the lack of socio-economic costs and environmental benefits (external costs) reflected in economic analysis of a CAD plant hinder the biogas deployment in Greece.

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