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The Role of Municipalities, Energy Companies and the Agricultural Sector in Denmark as Drivers for Biogas: Trends in the Current Development

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Abstract: *This paper examines the barriers to implementing biogas plants in Denmark and highlights advantages and barriers of the technology with a focus on the environment, energy and the agriculture. The article is based on a detailed study of development trends within the Danish biogas sector and identifies the most important current barriers for the biogas technology namely, difficulties in providing organic industrial waste, unfavorable funding options and low plant profitability. An element in overcoming these barriers concerns the inclusion of stakeholders from the energy sector and engaging municipalities more actively in the biogas development. Based on the analysis of the current situation and of the challenges and opportunities for the Danish Biogas sector, we propose that municipalities, energy companies and the agricultural sector take renewed actions and become drivers for the biogas sector. We identify trends in biogas development and provide suggestions for new stakeholder actions. Municipalities must, for example, facilitate access to new sources of raw materials, enhance energy planning by targeting biogas in their e.g. municipal heat planning. Energy companies should also benefit from the new market opportunities that biogas poses e.g. supply biogas for transportation purposes. Farmers must look for alternative ways of implementing biogas plants using new corporate design concepts rather than traditional centralized and farm biogas plants.*

Key words: *Biogas, Denmark, municipalities, renewable energy, energy companies, agriculture.*

1. Introduction

The European economy is facing a number of environmental, social and economic challenges, one of the most important being the reduction of greenhouse gas (GHG) emissions. The European Commission has proposed a roadmap for moving to a low carbon economy by 2050 (EU, 2011a) which implies a reduction of GHG emissions and energy savings. The roadmap is a part of the long term policy plans launched under the 'Resource Efficient Europe flagship initiative' (EU, 2011b), and aims at improving the competitiveness of the European economy by utilizing resources more efficiently, generating less waste and reducing the environmental impacts. A cornerstone of this policy is the idea of a circular economy (EU, 2014) in which the "take-make-dispose" economic model is replaced with one in which resources are recycled (McArthur, 2014). One way to organize such resource efficient and circular systems is through advanced biogas technology systems, which produce methane gas out of organic materials (Lybæk, 2014). The gas can be used to substitute fossil fuels and thereby contribute to the reduction of GHG emissions, but the technology also possesses other features that may function to fulfill the wider policy targets for a resource efficient, circular economy, e.g. soil improvements, recirculation of nutrients and lower pollution of the aquatic environment, etc.

Biogas systems are deployed in many European countries of which Germany has more than 7,700 biogas plants and a total installed capacity approaching 3,500 MW (FNR, 2014). The German biogas sector has seen a rapid development over the last 10 years induced by a profitable feed-in tariff. This incentive system has led to the installation of a comprehensive biogas production system primarily based on manure and maize silage (Ibid.). Other countries like Denmark, Austria, Sweden, Great Britain and Italy also have well-established biogas sectors, each having their own type of biogas systems (Piccinini, 2009). Sweden currently has 229 operating biogas facilities of which the majority is sewage treatment plants (Fallde and Eklund, 2014). There are also a number of biogas plants based on a combination of organic industrial waste and manure, plus a number of plants where organic household waste is fermented to produce biogas (Olsson and Fallde, 2014). A characteristic of the Swedish biogas sector is that a large percentage (44 %) of the biogas production is utilized as vehicle fuel in the transport sector (Fallde and Eklund, 2014). Great Britain has a well established biogas system in which biogas is recovered from MSW (Municipal Solid Waste) landfill sites (Piccinini, 2009). The British MSW landfill biogas technology is a fairly low-tech system compared to the more advanced Swedish and German biogas systems.

The major aim of this article is to discuss the main challenges facing the Danish biogas sector and second to explore potential trends and thus solutions to and opportunities produced by these challenges. The article focusses on the role of municipalities, energy companies and the agricultural sector. Thus we investigate recent trends in the Danish biogas sector. The Danish manure-based biogas sector consists of some 22 larger biogas facilities, approximately 45 smaller farm based biogas plants and a number of biogas facilities based on wastewater. Most of the plants produce combined heat and power (CHP) and the total amount of energy produced was 4.2 PJ in 2012 (DEA, 2013a). The national policy objective is to expand biogas production to 20 PJ by 2020 (Danish Government, 2012). Historically, the Danish biogas plants have been linked closely to the stakeholders in the agricultural sector (Raven and Gregersen, 2007), but since the financial crisis in 2007, the investment capacity of the sector has been restricted, leading to a situation where the expansion of the biogas sector by Danish agriculture is unlikely to take place, regardless of the incentive programs put in place by the national government.

The local government's role in energy planning has been emphasized in a number of studies (Corfee-Morlot et. al., 2009; Sperling et. al., 2011; Bulkeley, 2013) and, in terms of achieving sustainability, was acknowledged already in 1992 with the Rio Earth Summit's adoption of the Agenda 21 action plan (UN, 1992). Since then, a number of programs and projects have been launched in order to encourage and support local governments in their endeavor to plan for sustainable development such as the Aalborg Charter, Covenant of Mayer's, and C40. Biogas is a key renewable energy technology that often plays an important role especially within municipalities with larger areas designated for agricultural use.

1.1 The Role of Municipalities

As a result of the 2007 structural reform, the number of municipalities was reduced from 275 to 98, the reform gave the municipalities increased responsibility over environmental and planning issues. Danish municipalities have recently helped to achieve a national target by pointing out areas where centralized biogas plants could be established, however, only a few new plants have seen the light of day. Municipalities are also responsible for legal administrative and environmental procedures (for example Environmental Impact Assessments, EIA) connected to biogas proposals, but mostly as authority 'approving-work'. Thus, there is a need for municipalities to provide an enhanced planning framework and become active drivers in supporting biogas (Bjerg and Fredenslund, 2014).

Corfee-Morlet et. al. (2009) define four modes of governance by which local governments can implement climate change policies: 1) Self-governing - the municipality as consumer, 2) Governing through enabling - the municipality as a facilitator 3) Governing by provision - the municipality as provider, and 4) Governing by authority - the municipality as regulator (Corfee-Morlet et. al., 2009). We shall discuss each in turn.

Self-governing - the municipality as consumer
Municipalities typically have a large energy consumption of their own associated with the operation and management of offices, schools, kindergartens, nursing homes etc. Many municipalities have formulated energy saving policies and plans to reduce their energy consumption. Municipalities can also implement climate change policies through green public procurement (Sandén and Jonasson, 2005). For example, some municipalities operate biogas driven city busses and thereby create a market for upgraded biogas. This is the case in a number of municipalities in Sweden (Fallde and Eklund, 2014; Lantz, 2013).

Governing through enabling - the municipality as a facilitator
Municipalities very often play an important role as facilitator when new biogas projects are formulated. Municipalities could be both drivers and facilitators initiating actions and engaging relevant local stakeholders around biogas in their communities. Some municipalities such as Lemvig, Ringkøbing-Skjern and Thisted have been very active drivers initiating biogas development and facilitating processes, etc. Again, other municipalities, which also have large manure potentials due to a high number of livestock, are not very engaged in biogas production; some taking a facilitating role if required and some not being active at all regardless of the manure potentials, e.g. Varde, Tønder, Viborg, Vejen and Aabenraa (DEA, 2013).

Governing by provision - the municipality as provider
Municipalities can influence the expansion of the biogas sector through the provision of direct services, such as electricity, district heating, transport or waste management. Municipalities can influence electricity and heat supply through direct ownership, or majority shares in utilities, landfill sites, waste companies or public transport companies etc. (Corfee-Morlet et. al., 2009). In Denmark, for example, the company BioVækst produces biogas from organic household waste in a dry process (Møller, 2012). Biovækst is partly owned by municipalities through the two waste companies Kara/Novoren and Vestforbrændingen.

Governing by authority - the municipality as regulator
Municipalities have a number of tasks associated with the role of authority that directly influence biogas projects. This involves planning tasks and activities associated with the issuing of plans such as EIAs, municipal spatial plans, local spatial planning, as well as the issuing of a set of permits such as construction and digging permits, environmental permits and waste water permits (Tybirk, 2012). Such planning activities usually imply public hearings and communication with other public authorities that are influenced by the biogas project (Bjerg and Fredenslund, 2014).

As a part of the planning activities mentioned above, the government has recently demanded that municipalities suggest relevant sites for locating biogas plants in their municipal spatial plans in order to make it easier for stakeholders to set up and undertake biogas projects. The status ultimo 2013 shows that 40 out of 98 municipalities in Denmark have pointed out areas for locating biogas plants in their municipal plans, and that another 30 support the implementation of biogas in their community (DEA, 2013). This support is, however, primarily a statement of interest and no active engagement in promoting biogas follows automatically (Jørgensen, 2013).

1.2 The Role of Energy Companies & Agricultural Sector

In addition to municipalities, new stakeholders such as energy companies could also be involved in biogas development. Until recently, however, they have had a marginal role in the biogas sector in Denmark, compared to other countries in Europe. Within the last one or two years, the role of energy companies has however shifted as they have become engaged in biogas development. The question is what type of activities the energy companies currently are involved in and which unused opportunities still remain? Until recently, farmers and their organizations were the main drivers within the biogas sector, but financial restrictions have become very strong recently and have hampered their role (Gregersen, 2013). New types of engagement from the agricultural sector would however benefit biogas development and create new opportunities within the sector. Thus, looking at the latest trends in biogas development will provide an overview of which new opportunities the above stakeholders can provide.

2. Methodology

This paper *firstly* identifies the most important present and future biogas stakeholders, and outlines the major barriers for the biogas sector. *Secondly*, to overcome the identified barriers and point to new opportunities/relevant actions by identified stakeholders, the latest trends in biogas development are emphasized, these include number of plants established, ownership, concepts, use of biomass, energy production etc. *Thirdly*, we analyze *if* and *how* these stakeholders can revitalize the biogas sector by overcoming some of the implementation barriers, and investigate whether they exploit the opportunities identified within the sector. Opportunities are identified in the analysis, and illustrated as examples. As far as the municipalities are concerned, we have applied Corfee-Morlet et. al.'s (2009) four modes of governance by which local governments can implement climate change policies, as 1) Self-governing - the municipality as consumer, 2) Governing through enabling - the municipality as a facilitator 3) Governing by provision - the municipality as provider, and 4) Governing by authority - the municipality as regulator (Corfee-Morlet et. al., 2009). Within this framework we will exemplify opportunities within the municipal sphere to support biogas. As far as energy companies and the agricultural sector are concerned, we will take our point of departure in the latest biogas plants established, and analyze whether opportunities for developing the biogas sector are deployed, and whether barriers for the biogas sector are sought overcome.

Data sources include literature studies (peer reviewed articles, books and reports on biogas), interviews with experts within the biogas sector, as well as research within the biogas sector undertaken by the present authors over a period of several years. All the experts drawn upon here work within the field of biogas, either as planners, consultants and governmental actors with state-of-the-art knowledge of barriers and possibilities for the biogas sector to evolve. These include a) Anders Dyrelund; Consultant in Rambøll, Energy and Heat planner, b) Anders Fredenslund; Biogas expert in the Ministry of Natural Conservation, c) Kurt Hjort Gregersen; Biogas expert in AgroTech, and d) Peter Jørgensen; Consultant in PlanEnergi.

To strengthen the municipal role in biogas development we will, among others, identify the perspectives in the newly launched 'Resource Strategy' and the potentials of using alternative types of organic waste, to provide new gas boosters. The latter could for example overcome the barrier connected with lack of organic industrial waste - enhancing gas yields - and give municipalities a new role in biogas development. Thus, the role of municipalities as *facilitators and regulators* will be identified and examples provided relating to their future role as drivers. Energy companies could also take part in the biogas sector, and we examine what interest they have in doing so. When seeing biogas as a new market opportunity, providing gas for transportation and upgrading biogas for the natural gas network, new business opportunities could arise for energy companies. This would help overcome the current barrier of a relatively limited market for biogas. Additionally, existing stakeholders in the biogas sector, namely farmers and their organizations, could join together and implement alternative biogas plants, as opposed to the traditional farm and centralized biogas plants. Suggestions concerning new concepts of corporate design will thus be offered, which potentially could overcome the barrier of identifying appropriate sites for large-scale centralized plants.

3. Biogas Production and Type of Plants Implemented

Danish manure based biogas plants currently account for one third of the biogas plants established, whereas the remaining two thirds are municipal wastewater treatment plants, industrial plants, and landfill gas sites. The energy production from these plants accounts for approximately 4.2 PJ, or 0.5 % of the current energy consumption, but the potentials are estimated to be 10 fold, thus 42 PJ (DEA, 2014). Biogas production is separated on the basis of the following types of biogas technology (Ibid.):

- 60 municipal wastewater treatment plants
- 5 industrial plants

- 25 landfill sites
- 20 centralized biogas plants
- 45 farm biogas plants

The manure based plants consist of two corporate design concepts; a) large scale centralized biogas plants with several farmers connected to them, they deliver livestock manure. The biogas is converted in a motor/generator and distributed as electricity on the grid, and as district heating to a local community. Alternatively, the gas is distributed to a nearby natural gas CHP plant, and then converted to electricity and heat for district heating purposes. Another concept is b) farm biogas plants implemented directly in connection to a larger livestock farm, e.g. a pig farm. Here the biogas is converted in a motor/generator for electricity and heat production, but with a limited heat distribution due to the farm's relatively small heat demand. The heat will most often just cover internal heat demands in stables and farmhouses, and surplus heat will normally be wasted (Lybæk et. al., 2013). The Danish Government supports the implementation of biogas technology by high feed-in tariffs on electricity and by giving subsidies to investments, as they have many environmental, energy and agricultural related benefits (DEA, 2014). Below we have outlined some of the benefits and drawbacks in regards to biogas.

3.1 Challenges for the Biogas Sector

As emphasized in Table 1 below, there are numerous benefits connected to biogas in Denmark. Despite the advantages of the biogas technology, several factors have hampered further development of the technology - also outlined in the table - within the last, approximately, 10 years. The most important barriers are presented more thoroughly below, but are chosen because they are regarded as vital for a future dissemination of the biogas technology (DEA, 2013; Gregersen, 2103; Jørgensen, 2013). Thus, larger markets for the distribution of biogas are needed and new capital flows required, just as

Table 1: *Advantages and disadvantages of biogas.*

	Advantages	**Disadvantages**
Environment	-Biogas plants reduce emissions of methane and nitrous oxide from manure management, and thus -Lower GHG emissions into the atmosphere. -Recirculate organic materials and waste etc. for soil fertilization. -Reduce nutrient pollution of the quatic environment by enhanced manure uptake through the crops. -Lower air pollution (smell) when bringing out digested manure.	-Risk of methane leaks from gas storage. -Manure spills to the environment from manure storage facilities a risk. -Increase in noise, dust and road damages as a consequence of manure transportation, and thus -Public resistance towards large centralized biogas plants is widespread.
Energy	-High burning value fuel. -Biogas is a domestic renewable energy source, which increases energy security, and -Reduce the need for import of fossil fuels like coal and natural gas. -Can be used for a variety of energy purposes – including use for transportation. -The gas can be stored and used when needed, e.g. when wind energy production is low and a quick back-up fuel is needed.	-Biogas has relatively limited potentials (≈ 40 PJ in Denmark) and can only cover a minor part of the need for renewable energy for transport and energy supply services in the future. -Expensive to upgrade to natural gas, and for transportation usage. -Markets for sale of biogas/heat limited. -Energy output limited due to lack of access to industrial biogas-boosters; thus the agricultural substrates provide a lower gas yield compared to industrial waste.

Agriculture	-Better image in the agricultural sector when the environmental pollution is reduced. -Lower costs connected with purchase of artificial fertilizers. -Higher value fertilizer when the manure has been digested.	-No reliable and low-cost alternative to industrial gas-boosters is yet provided by the agricultural sector.
Financial issues	-New jobs in rural areas when building and operation the biogas plants. -Biogas can provide farmers with a higher economic robustness if prices on fossils fuels and crops increase, as they have additional income from biogas.	-High plant investments and relatively low profitability. -Favorable loan opportunities are difficult to obtain. -Farmers reluctant to join biogas plants as they focus on return on investment, and not only on receiving back valuable digested manure. -The timeframe of implementing a centralized biogas plant is very long (5-10 years).

Source: Jørgensen (2009); IEA Bioenergy (2013); Lybæk (2014)

higher gas yields through the use of alternative gas boosters could provide higher plant profitability. The issue of where to implement large centralized biogas plants is also currently hampering a further development of the biogas sector.

3.2 Identification of Important Barriers

Gas boosters
Previously biogas plants used protein rich organic industrial waste (like slaughterhouse waste and fish residues etc.) to increase gas yield and thus to improve plant profitability. Today the majority of such organic industrial waste is already utilized in existing plants (Jørgensen, 2013 & Gregersen, 2013). An increase of anaerobic digestion of manure therefore requires other types of gas boosters or new types of plant designs to cope with the lack of gas boosters. Hence, municipalities in particular could help the biogas sector by identifying such gas boosters, and enhance their energy planning to support biogas.

Markets
There is also a need to expand the existing market for biogas which is currently limited to the local community, through distribution of district heating or biogas sent to a larger CHP plant in the area. New market opportunities for biogas would favor the development of the biogas sector (Lybæk et. al., 2014a). Thus, for example, municipal support to establish e.g. separate non-upgraded biogas pipes in the community could be applied, just as energy companies could upgrade biogas for usage in the existing natural gas network, or for transportation.

Public resistance
Another important barrier is finding suitable locations for new large scale centralized biogas plants. Local communities resist the idea of such plants, due to a combination of fear of odor pollution, heavy truck transportation of manure - leading to dust and noise - and due to the visual pollution from the erected biogas plant (Bjerg and Fredenslund, 2014). Thus, new types of biogas plants based on other corporate design concepts might reduce these problems by avoiding heavy road transportation etc.

Investments
Stakeholders pushing the biogas sector forward have historically been the agricultural sector (farmers and their organizations). But the financial crisis starting in 2007 also hit the agricultural sector and reduced investment ability (Gregersen, 2013). Hence, new stakeholders - like energy companies - should be involved and through investments push biogas forward, seek new market opportunities and means of engagement. Farmers and their organizations, on the other hand, could look to new and less costly biogas corporate design-concepts to increase the dissemination of the technology, as mentioned above. In this way the agricultural sector could revitalize their role as drivers within the biogas sector.

4. Analysis of Development Trends in the Danish Biogas Sector

In the following we will look at the role of municipalities, energy companies and the agricultural sector, as far as trends in the current development of biogas in Denmark are concerned. We will identify existing trends that can underline these stakeholders as potential drivers, but also look at opportunities and propose actions not yet taken by these actors. We will provide concrete examples to emphasize the above. The section begins with an introduction (Table 2 below) to the most recent biogas plants established or scheduled to be established. In addition to the centralized biogas plants outlined in the table, several farm biogas plants will be implemented within the next few years, especially within Ringkøbing-Skjern Municipality. Here there will be a piping of gas from several small farm plants to one larger CHP unit. The trend is, however, to establish large-scale centralized biogas plants.

4.1 The Future Role of Municipalities

To overcome some of the barriers mentioned earlier, we suggest that municipalities should be engaged in providing biomass gas-boosters, such as organic waste from, for example, source separated household waste and biomass from municipal areas (from parks, roadsides, natural care), and if possible also blue biomass in municipalities located near coastal areas. As emphasized in Table 2 below, the trend is to feed the biogas plants with organic boosters: energy crops, straw, and different types of organic wastes that are redistributed from a previous re-use (Fredenslund 2014). Thus, it is important to strengthen the supply of organic waste to support a continuous expansion of manure-based biogas plants in Denmark.

We suggest that municipalities engage more actively in promoting a local biogas infrastructure, pipes etc., either as separate solutions or as a part of their existing network. Hence, support the build-up of a local gas infrastructure for non-upgraded biogas. This will create a larger local market for distributed biogas.

As far as energy planning is concerned, we suggest an enhanced focus on including biogas more actively in the municipal heat planning, as well as in a strategic energy planning, which we define as

Table 2: *Trends in biogas plants establishment.* Source: Fredenslund, 2014

Biogas plant	Input -type	Input 1,000 t/y	Gas mio. CH4 m3/y	Energy use	Status
Horsens Bio-energi A/S	Manure, slaughterhouse waste & other organic wastes	240	10.0	Gas grid injection	In operation 2014
Solrød Biogas A/S	Organic industrial waste, manure & seaweed from beach cleaning	200	6.0	Combined heat and power	Construction initiated 2014
ENVO Biogas Tønder A/S	Manure, energy crops, organic waste, sludge	922	36.2	Gas grid injection	Construction initiated 2014
NGF Nature Energy Holsted	Manure, energy crops, organic waste	393	12.0	Gas grid injection	Construction initiated 2014
NGF Nature Energy Nordfyn	Manure, energy crops, organic waste	315	9.0	Gas grid injection	Construction initiated 2014
NGF Nature Energy Midtfyn	Manure, energy crops, organic waste	365	10.0	Gas grid injection	Construction initiated 2014
Madsen Bio-energi	Manure, energy crops, straw	118	3.1	Gas grid injection	In operation 2014

Source: Fredenslund, 2014

robust, long-term, and integrated elements from all three links in the energy planning (energy resources, energy production and energy demand). Enhancing the focus on biogas in planning processes could support the implementation and distribution of biogas, and support that local CHP plants can utilize the biogas.

In addition to the actions mentioned above, which will be exemplified further below, municipalities could also actively support new biogas markets by requiring local CHP plants to utilize the biogas through the 'Law of Heat Supply', and by other means prioritize biogas higher, e.g. through municipal assistance in calculations regarding the value of biogas in different supply-scenarios, and by supporting and facilitating negotiations when undertaking supply contracts, etc. We also suggest that a support grant to actually plan for the implementation of biogas plants should be available. This is, for instance, the case for windmills, where financial support from the government is provided in the initial phase of the planning for the erection of windmills in local communities. Grants could also be provided for setting up the before mentioned local non-upgraded biogas networks, such as the Ringkøbing-Skjern network mentioned below. This could support the buildup of a local gas infrastructure, making biogas projects more economically viable due to the enlarged local market. Finally, municipalities can also promote biogas if they base their municipal vehicles fleet on biogas instead of traditional diesel (see section 4.2.2 below).

4.1.1 Examples

Municipal supply of biomass gas-boosters

At the end of 2013 the Danish Government launched its 'Resource Strategy' as an alternative to previous waste strategies. As the title indicates, it maintained that more focus should be on looking at waste as a resource as opposed to simply being waste, and the governmental target is a 50 % reuse of organic household waste before 2022. This implies that the current reuse of approximately 50,000 tonnes organic waste will increase to 300,000 tonnes in this period. This means that by the year 2022 around 800,000 tonnes of waste will no longer need to be incinerated (Danish Government, 2013). Some municipalities will be quite challenged by this, whereas others - for example Billund Municipality - have implemented source separated household waste providing citizens with two different waste bins. This has been underway for several years (Vetter, 2013b).

Thus, in Billund the organic waste is mixed with livestock manure at a centralized biogas plant, and used for energy production and finally as fertilizer. There are many possibilities in using municipal organic waste from households etc. to boost the gas production on future Danish biogas plants. Learning from Billund, and from our neighboring countries like Sweden and Norway, this method should be promoted at the municipal level. With the 'Resource Strategy' mentioned, municipalities would have a stronger incentive to recycle organic fractions from their municipal waste, and thus find the implementation of local biogas plants more attractive in the future.

Municipal blue biomass is a new emerging resource for biogas production and is in its very infancy, not only in Denmark but also globally. Blue biomass is a common name for biomass extracted from the sea or harvested on land in ponds, either macro or micro algae. Blue biomass does not compete with food for animals or humans, as opposed to beet or maize currently co-digested with manure on some biogas plants in Denmark. The possibilities of using blue biomass for energy purposes are still being researched and several projects are looking at different types of algae as feedstock for anaerobic digestion (Laurentius, 2012).

The new biogas plant at Solrød (see Table 2) on the island of Zealand makes use of seaweed as a biomass resource for boosting gas production. Cast seaweed forms a huge environmental problem on Køge beach due to the bad smell it produces when decomposing. The new biogas plant will roughly utilize 22,000 tonnes of collected seaweed annually, in combination with livestock manure corresponding to 53,000 tonnes, as well as 80,000 tonnes of organic waste from a pectin industry. This will provide a net energy production of around 9 billion m^3 biogas (distributed as 29 GWh heat and 25 GWh electricity) equal to CO_2 emission reductions of 40,500 tonnes, and save the environment from 62 tonnes of nitrogen being leached from seaweed decomposing on the beach (Fredenslund, 2011).

The municipality of Solrød has been a very strong stakeholder in initiating the idea of the Solrød biogas plant, and thus planning for the use of seaweed as a gas booster. They have participated actively in and facilitated the process around the biogas plant, and enabled relevant stakeholders to cooperate, etc. Given the enormous Danish coast line, it should be possible to use blue biomass for energy production in other municipalities in the future, and not only in Solrød. Thisted is another very active municipality as far as providing knowledge of local biomass resources for biogas plants besides manure. The municipality has mapped the available resources in their community in order to support decisions regarding implementation of new biogas plants (Thisted Kommune, 2012).

Local biogas infrastructure
Ringkøbing-Skjern municipality in North of Jutland has developed a strategy where biogas from approximately 60 small-scale biogas plants will be distributed over an area of approximately 200 km, as non-upgraded gas, in pipelines into urban CHP plants. Here, the electricity and heat are produced efficiently for a local market. The strategy also includes two large biogas plants for the treatment of more difficult biomass waste, such as waste from commerce, fiber fractions from manure and organic source separated household waste (Ringkøbing-Skjern, 2013). Piping gas instead of transporting manure by means of trucks is also beneficial for the environment, meaning that only valuable biogas - not thin manure - is moved over greater distances through pipes. Thus, by building a local biogas infrastructure, a much larger market for biogas from farm-scale plants will be available.

Enhanced energy planning
Heat planning supporting biogas can be applied by municipalities by identifying gas engines running on, for example, natural gas and hence convert them to run on biogas from a local biogas plant. Planning concerns the identification of such sites and hence places the biogas plant near the gas engine thus phasing out the use of fossil fuels. Such gas engines could, for instance, be local CHP plants providing energy to a local community, or a larger industrial application using gas in its manufacturing processes; thus natural gas is replaced by local biogas. An example of the first is the small town of Hashøj in which an existing gas engine running on natural gas was converted to biogas use after Hashøj centralized biogas plant was established by nearby farmers (Dyrelund, 2013). Another aspect of planning could be to identify new housing areas in municipalities (expanding residential areas), where biogas can supply energy instead of an extension of the district heating network. It could also be to identify whether biogas might replace natural gas in already established residential areas.

As far as strategic energy planning initiatives for biogas are concerned, we find it important that the planning *also* happens across municipal borders to ensure that all types of potential biomass are being identified and thus utilized. If very large centralized biogas plants are, for example, scheduled to be implemented in one municipality, it can potentially hamper the development of more decentralized plants in another part of the region, as the biomass will already be in use. Thus, a dialogue between relevant municipal stakeholders is required. Municipal strategic energy planning can also be used to support biogas in a long-term perspective, by formulating targets for energy supply in the short, middle and long run as far as energy use, type of utilities and choice of fuel are concerned. It could for instance be materialized as a target of using biogas in the municipal heat supply for the next 20 years, and then go for upgraded biogas distributed on the larger natural gas network across borders in the region when economically feasible. This will provide biogas interested stakeholders with an idea of the political framework conditions for biogas in the municipality.

4.1.2 Reflections on the Role of Municipalities
To support biogas development, municipalities can act as *facilitators* by assisting in locating/mapping alternative gas boosters such as blue biomass or, for example, biomass from nature areas. Municipalities can also facilitate the supply of organic source separated household waste etc. to biogas plants. Supporting biogas is also an opportunity for municipalities to enable a transition from the use of natural gas to biogas by focusing on industries/energy utilities that could substitute their type of energy usage; thus enhancing their energy planning activities. Furthermore, municipalities can also support a local gas infrastructure of non-upgraded biogas, which will enhance a more developed market for biogas locally. Opportunities also exist for providing municipal support regarding supply scenarios, and for develop-

ing a fund from which grants can be acquired for planning the implementation of biogas plants. As a *regulator,* the municipality can moreover force local CHP plants to use biogas instead of e.g. natural gas or biomass.

Thus, realizing the roles above could assist in reducing some of the barriers to biogas usage highlighted above such as lack of gas boosters, limited markets for biogas, etc.

4.2 The Future Role of Energy Companies

Up until recently Danish energy companies had little or no role in the implementation of biogas plants. This contrasts with, for example, the implementation of windmills, where energy companies for many years have been very active, especially when it comes to off shore installations in windmill parks. Danish natural gas companies should, however, be more involved in biogas production in the future to keep up their market share and to develop an alternative commodity to the exhaustible natural gas resources extracted in the Danish part of the North Sea. Below we outline some actions which energy companies can take in promoting biogas; some are already identified as new trends (see Table 2).

4.2.1 Distribute Biogas on the Natural Gas Network

Biogas can be upgraded and cleaned to natural gas standards, named bio-methane gas, and distributed on the widespread natural gas network providing energy to households and industry. To achieve natural gas standards biogas has to be cleaned for CO_2 and pressurized, etc. Today, bio-methane gas can be certified by the Danish transmission system operator Energinet.dk, which guaranties that the bio-methane gas substitutes fossil fuel like natural gas and thus results in CO_2 emission reductions. The certification makes it possible for the energy consumers to track down the origin of the bio-methane gas all along the supply chain (Vetter, 2013a). The latest development is that two out of three natural gas distributers in Denmark now offer certified bio-methane gas to their customers (see below). Municipalities, including households and industry etc., could thus be interested in purchasing this type of green energy, even though the costs will be higher due to upgrading expenses of approximately 0.5-0.6 DKK/ m^3. Looking further into the future, it could also be a possibility for energy companies to export certificated bio-methane gas across borders, as presently done with electricity produced as certified 'green electricity'.

4.2.2 Biogas for Transportation

Biogas for transportation is still in its infancy in Denmark compared to Sweden, and currently there is only one gas station, in Copenhagen, for vehicles to fill their tanks with conventional natural gas (E.ON & OK, 2014). As shown in Table 2, the trend of utilizing biogas for transportation purposes is not yet used in the already implemented and scheduled plants. A large vehicle fleet could however initiate a further development of biogas for transportation; for instance a large taxi company. This could potentially create a market for bio-methane gas or a mix of natural gas and bio-methane gas, as opposed to conventional natural gas. The well-disseminated gas network could thus provide the basis for an infrastructure of gas stations throughout the country. Economic and subsidy related issues will also have to be improved in a Danish context, as gas vehicles currently are more expensive than diesel vehicles, just as grants would be required to establish a gas station infrastructure (COWI, 2013).

4.2.3 Examples

In the following we will provide a few examples showing the trends in engagement in biogas by energy companies, and emphasizing their potentials as an important future stakeholder.

DONG Energy

DONG Energy distributes bio-methane gas from its upgrading facility in Frederica to an ice-cream manufacturer Hansen Ice-cream. The gas originates from a wastewater treatment facility, and is the only plant in Denmark upgrading biogas to natural gas standards. The initiative is part of a 'climate partnership' between DONG and Hansen Ice-cream, which focuses on energy savings and the use of climate friendly energy. The certification system means that the ice-cream manufacturer can prove its environmental concern, and thus a part of the company's Corporate Social Responsibility (CSR) strategy. The purchase of bio-methane gas is an extension of an existing partnership with the energy company, from which Hansen Ice-cream has purchased certified electricity from windmills for several years (Vetter, 2013a).

NGF Nature Energy
This stakeholder is currently engaged in the implementation of livestock based biogas plants in Denmark. 'NGF Nature Energy' has for example, together with local farmers in Holsted, Jutland, scheduled the implementation of new centralized biogas plants providing upgraded biogas to around 2,000 citizens through the already established natural gas network. The biogas plants will digest approximately 275,000 tonnes manure annually plus additional biomass corresponding to 118,000 tonnes. This will provide bio-methane gas amounting to 11-13 billion m^3, and contribute to many of the environmental, energy and agricultural related benefits of biogas presented earlier (NFG Nature Energy, 2014). The plant can provide 150 short-term jobs (construction phase) and 25 long term jobs (operation and maintenance) in an outskirt area of Denmark that lack development (Vetter, 2012). Apart from the plant mentioned above another two biogas plants are scheduled to be implemented by NGF Nature Energy in the northern and southern part of Funen (see Table 2).

HMN Natural Gas
A large survey of the possibilities of using bio-methane gas for transport is currently initiated by several stakeholders in North Jutland. HMN Natural Gas, together with e.g. North Jutland Traffic Company, Region North Jutland, as well as the Frederikshavn municipality and later on Aalborg municipality, will investigate how to convert public bus transportation and the waste renovation fleet from using diesel to bio-methane gas in the long run. The investigation is expected to lead to the implementation of a gas station infrastructure along the E45 motorway; thus two gas stations placed in Frederikshavn and Aalborg, respectively. These gas stations will also facilitate a transport corridor between neighbor countries like Sweden and Germany, and thus provide infrastructure for gas vehicles. The project has been initiated as a consequence of the Energy Funen biogas plant (described above), which will be implemented in the area providing bio-methane gas to the Region (Pedersen, 2013).

4.2.4 Reflections on Energy Companies

Energy companies in Denmark are progressing and their role in biogas development is approaching that of many other countries within the EU such as Germany and Sweden. This is understood in the sense that energy companies now actively engage in the biogas sector by upgrading biogas for distribution on gas networks. Compared to our neighboring countries biogas for transportation usage is still in its infancy, but conventional gas filling tanks are being implemented, so a future step using biogas is not unrealistic. A large vehicle fleet could however push the use of biogas for transportation forward, which is an opportunity not yet taken by energy companies or other organizations or companies with a large fleet.

Thus, energy companies now assist in reducing the barriers of limited markets for biogas, as well as providing new financial opportunities for the sector enabling it to expand. However, looking at corporate design, the trend is to establish large scale centralized biogas plants. This does not provide solutions to the challenges regarding local resistance within communities, caused by noise, dust and road transportation connected to such type of plants.

4.3 The Future Role of Agriculture

As mentioned earlier, the implementation of biogas plants was previously initiated by agricultural actors (farmers supported by their organizations) and materialized as either farm plants or large scale centralized plants. Table 2 outlines a trend in which energy companies now play a more important role in biogas implementation in collaboration with farmers. This is positive as far as providing new investment capital is concerned, but does not overcome some of the other barriers mentioned in Section 3.2. It is therefore necessary also to look at alternative ways of organizing the implementation of biogas, and this suggests new corporate design initiatives between farmers.

Besides the initiatives taken by Ringkøbing-Skjern municipality, we argue that other types of biogas deployment should be promoted. In Ringkøbing-Skjern an extensive local biogas infrastructure will be established, which will distribute biogas from up to 60 decentralized located farm plants in the municipality. This alternative corporate design concept between farmers is unique, and assists the biogas sector in overcoming the barrier of where to locate large scale centralized biogas plants. In the following, we have developed three new concepts of corporate design challenging the traditional types of biogas, the new designs can help to overcome some of the barriers mentioned.

4.3.1 Examples

Neighbor-model

This model focuses on distributing either manure or gas between two neighboring farms to lower the construction costs of implementing two separate biogas plants. In Option A, shown in Figure 1 below, manure is piped from farm #1 to farm #2 by means of manure pipes. To benefit from the heat, farm #1 can receive heat through heat pipes between the two farms. Livestock manure etc. is digested at farm #2, where the digester, technical house with motor/generators, gas storage etc. are placed. Surplus heat heats up the reactor tank, stables and farmhouse on farm #2, and possibly also on farm #1, if heat pipes, are established. In Option B manure is distributed from farm #1 to farm #2 with no energy services (heat) being received in return, thus lowering the cost of the scheme. Manure can either be piped or transported by trucks between the farms. In Option C biogas from farm #1 is distributed to farm #2 and then simply converted to energy on this farm. This will however require a higher investment at farm #1 where digester and gas blower are implemented in order to send gas to farm #2. The heat produced can thus be sent to farm #1 through heat pipes, as in Option A as mentioned earlier.

The model implies that the construction costs of implementing two separate farm biogas plants are avoided, and that smaller farms could also utilize their livestock manure for energy production. Moreover, the model expands the heat market as two farmers work together and thus the model limits the amount of surplus heat losses.

Star-model

This model allows up to 20 farmers to cooperate and pipe livestock manure from their individual farm to a central plant (therefore the name 'star model'), where it is digested and converted to energy as electricity and heat. Thus, farmers connected to this scheme do not convert manure into gas, but solely pipe it to a central facility. As shown in Figure 2 below, heat is firstly used to warm up reactor tanks and then distributed as district heating to the local community. The electricity produced is distributed on the national power grid. Farmers having a high heat demand in stables etc. will not benefit from the heat produced, as it primarily is distributed to the local community, but they could instead benefit from a favorable mix of pig and cattle manure with an optimal relationship between phosphorus and potassium.

Pig manure is rich in phosphorus and low in potassium, where the opposite is the case for cattle manure. Thus, a mix is favorable as soil fertilizer. Another benefit of this scheme, including the neighbor-model, is the limited need for road transportation. Thus, these models prevent extensive road transportation having impacts such as road wear and noise pollution in the local community. Farms with a large heat demand, for instance pig farms, will, however, not be able to substitute their energy consumption with biogas heat based on this model. It should be mentioned that if the local heat market is saturated, another option could be to upgrade the biogas and distribute it on the natural gas networks.

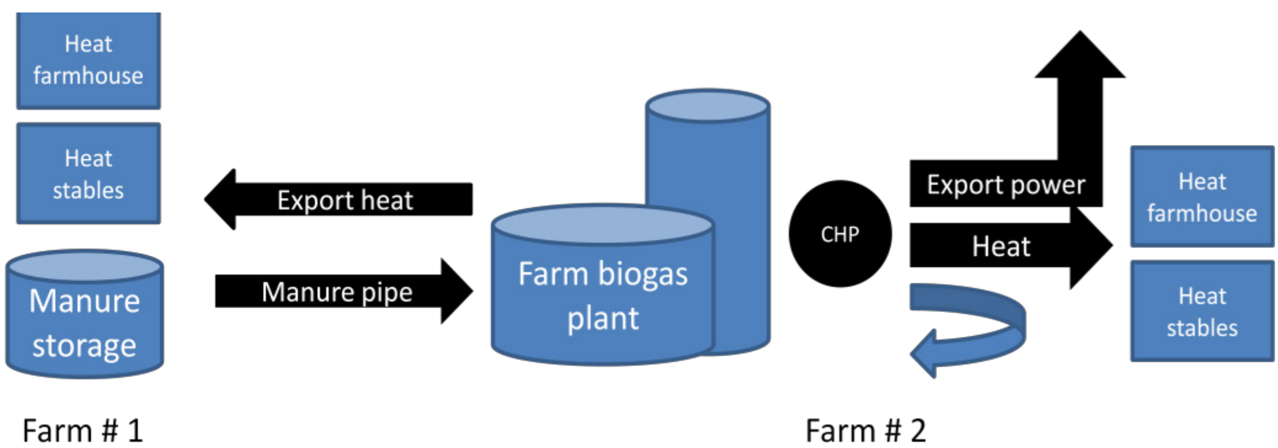

Fig. 1: *'Neighbor-model' showing Option A*

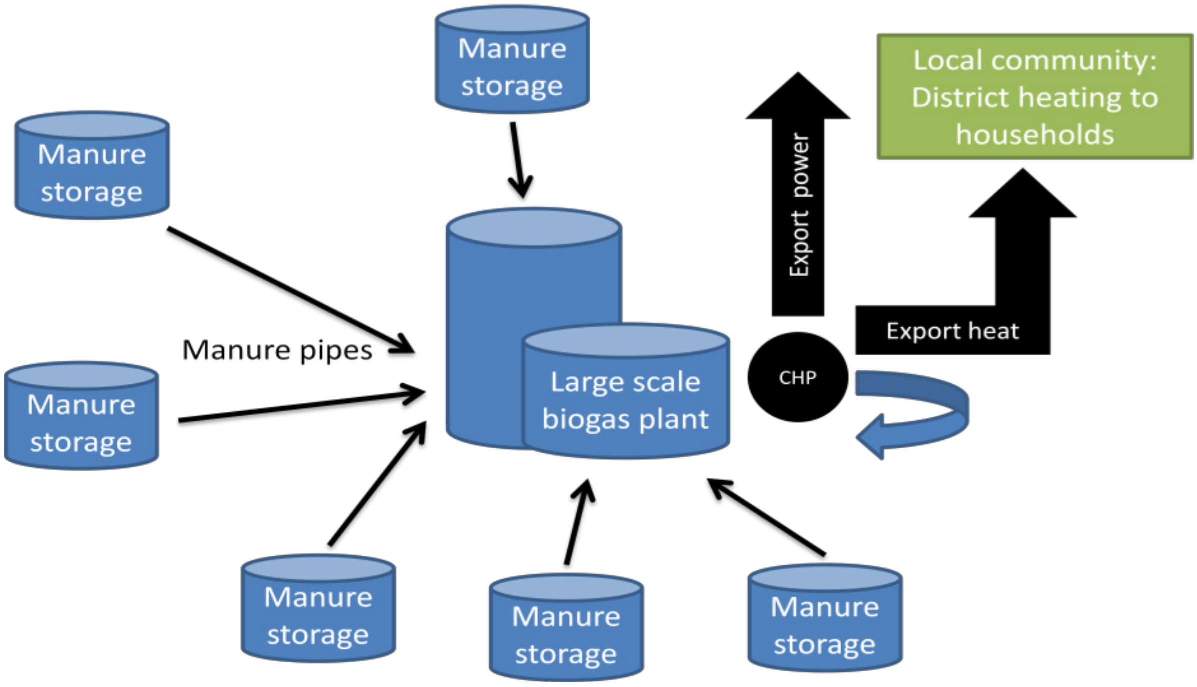

Fig. 2: *'Star-model' showing Option B*

Institutional-model

The last model, Option C, focuses on minimizing heat losses at farm biogas plants and is based on a corporate design concept between a farm and a larger heat market being an institution etc. in the local community. This is shown in Figure 3 below. A typical case would be a large pig farm with steady manure production throughout the year, and hence large amounts of surplus heat. In order to avoid such heat losses, cooperation with a nearby institution is utilized, such as a school, a public swimming pool, sports facility, or nursing home etc. Heat from the biogas plant will now substitute the cost from previous oil consumption, by heat being piped from the farm to the nearby institution.

4.3.2 Reflections on the Role of Agriculture

The corporate design concepts outlined above provide alternative solutions to the traditional concepts based on transport of manure, which causes dust, smell and rear of roads, etc. The concepts could thus ease the challenges regarding where to locate biogas plants, and reduce the visual pollution from very large scale centralized biogas plants. It also improves the plant profitability by providing markets for the sale of excess heat, and lower plant costs through sharing of expenses.

Thus, the suggested corporate design concepts assist in reducing barriers for biogas as visual pollution, noise, dust and smell, etc. Barriers for providing

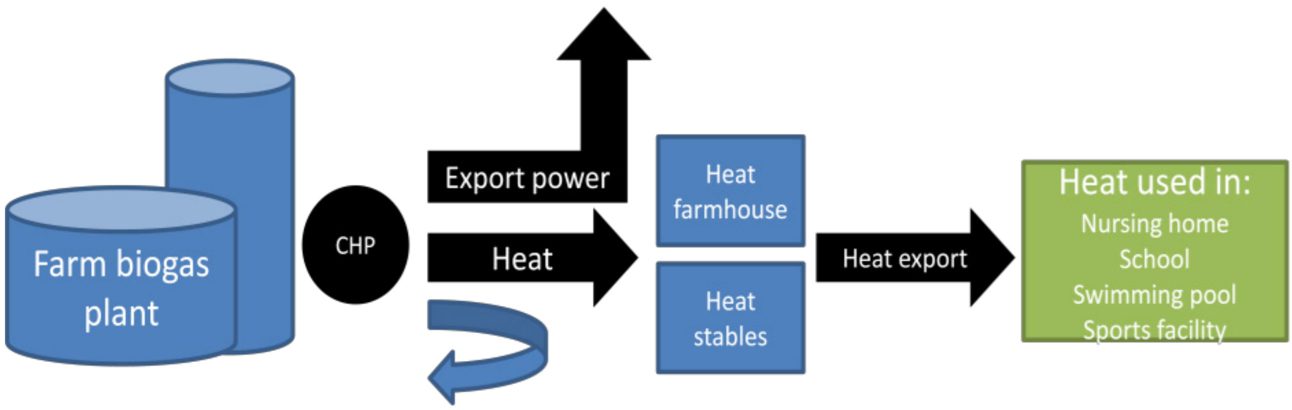

Fig. 3: *'Institutional-model' showing Option C*

finance for concepts not primarily focusing on upgrading biogas are, however, not overcome but could be integrated in the 'star-model'.

5. Discussion

The Danish biogas sector has moved from a situation in which farmers and their organizations were the main drivers of implementing farm based plants and centralized biogas plants. Due to the economic crisis resulting in limited investment capital, and other barriers such as lack of organic materials boosting gas yields, low plant profitability and difficulties in locating large scale biogas plants, the development has almost stopped for a period of 10 years. New trends in the biogas sector identified in this paper are however that energy companies now play an important role in the recently established plants that focus on upgrading biogas to the natural gas network. Energy companies inject new investment capital and join together with farmers not capable of taking any economic risk relating to biogas. The trend is to implement large scale centralized biogas plants where the gas is utilized in an existing natural gas network. The trend has not yet been to upgrade and pressurize gas for transportation, as is done in Sweden (Fallde and Eklund 2014).

The use of organic household waste is not yet applied on the plants implemented (though one plant in, BioVækst, does exist), which is connected to the fact that collecting and separating the waste is not yet in place within all Danish municipalities. The use of industrial organic waste applied on new biogas plants - despite a lack of such waste - is merely a consequence of a redistribution of existing industrial organic waste; not that new industrial waste is identified. The resources are therefore likely to become increasingly expensive. The same trend is seen in the use of energy crops, where large amounts are expected to be used within coming years. Due to regulation in the use of energy crops, and the expensive and limited amount of industrial waste, source separated household waste and other types of biomass (straw, clover grass, blue biomass, etc.) is likely to substitute the above.

The financial crisis has left the agricultural sector in a situation where the investment capability in new plants is limited. We proposed new concepts of corporate design that could impose new opportunities for farmers and their organization. An ideal situation would however be if Danish agriculture and energy companies worked together regarding the proposed concepts and not only on large scale centralized plants. The 'star-model' also provides an opportunity to upgrade biogas to the natural gas grid. The 'neighbor-model' and the 'institutional-model' could - depending on the size - be interesting for energy companies as far as local energy supply is within their distribution area.

It is very important that the role of municipalities is strengthened in Denmark. To be able to achieve the necessary biogas expansion, and to support the agricultural sector and energy companies, municipalities - as emphasized in this paper - can have a *facilitating* role. Many Danish municipalities are in a process of developing strategic energy plans. These plans bridge traditional separate areas of planning expertise within the municipalities (physical planning, heat planning, transport planning, waste planning etc.) and as such provide a new framework for climate change mitigation strategies. Facilitating a transition from the use of natural gas to biogas within industries/energy utilities is also a necessity, just as providing a local gas infrastructure of non-upgraded biogas - which will enhance a more developed market for biogas locally - is. Municipalities also play an important role as *regulators*, since the municipalities are the authority responsible of issuing environmental permits, and have to approve local spatial plans as well as environmental impact assessments when new biogas plants are planned. Finally, the municipalities in Denmark often have a joint ownership of energy companies (e.g. waste incineration plants, heat distribution companies and utilities) and can thereby influence priorities and investments thereby governing the biogas sector *by provision*.

6. Conclusion

This article analyzed the current and future development of the Danish biogas sector. The article identified that biogas stakeholders like municipalities, energy companies and the agricultural sector engage very differently in the biogas sector. These differences entail a room for improvement and learning. Municipalities could for instance enhance their energy planning targeting biogas e.g. raw material usage and municipal heat planning waste. Energy companies should benefit from the new market opportunities associated with the utilization of upgraded biogas in the natural gas grid. Farmers can provide completely new solutions when implementing biogas plants, through new corporate design concepts, as opposed to the traditional established centralized and farm biogas plants. We however stress that the support to biogas should happen in collaboration between the stakeholders identified to achieve the necessary synergies.

Traditionally, the Danish biogas sector has been constituted by the agricultural sector, but the economic crisis has restricted funding opportunities. With a biogas sector consisting of primarily manure-based plants, limited access to organic industrial waste boosting the gas yield, and a market for energy primarily composed by local CHP plants, the situation is now shifting relatively fast. As in neighboring countries such as Sweden and Germany new ownerships models are emerging, where energy companies play an important role. Biogas is increasingly being upgraded for distribution on the gas network. Organic household waste and alternative biomass will most likely supplement the large fraction of the industrial waste and energy crops currently being utilized.

Thus, the trend has been that the biogas sector is evolving in the direction of the biogas sectors in Germany and Sweden. A complete transition away from the production of CHP (as on small biogas plants in Germany due to very high feed in tariffs) is however not considered likely. If a local market for heat is available, it is most feasible to establish a biogas plant as a CHP plant, distributing district heating to the local community (Energinet.dk, 2010). However, plants designed and located in areas with a saturated or non-existing heat markets are likely to upgrade the biogas and inject it into the natural gas network. Thus, the implementation of the new corporate design concepts, suggested in this paper, is important.

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