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The Potential of Biogas as Vehicle Fuel in Europe

– A Technological Innovation Systems Analysis of the Emerging Bio-Methane Technology

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Abstract

Despite the many estimations of the biogas potential, there is a gap in research regarding current production volumes of biogas in Europe and the corresponding potential of bio-methane as a vehicle fuel. Therefore, this thesis' primary aim is to determine how much biogas that is produced within Europe at present and estimate how the biogas production may develop until 2015. The secondary purpose of this thesis is to analyse and identify the most important factors which are likely to decide whether this potential will be realized as a vehicle fuel or not.

Two different forecasts have been developed and discussed in order to determine the biogas production in 2015. According to the forecasts presented in this thesis, the biogas production in Europe may increase, from the current production of 6 Mtoe (million tons of oil equivalents) to 23 Mtoe by 2015. Although being the most progressive forecast, 23 Mtoe is in line with previous diffusion patterns of other renewable energy technologies and also in line with estimations made by the European Commission.

The future biogas production and usage will likely be highly influenced by policies. A number of driving forces have been identified for the production of biogas, such as climate change and fuel security. These issues have in turn resulted in new policies and targets for the use of renewable energy sources, which act as driving forces for the development of the production and use of biogas. However, a number of blocking factors for realizing its potential as a vehicle fuel have been revealed. One severe blocking factor is the weak formation of networks and advocacy coalitions. Combined with lacking infrastructure, it imposes great obstacles for the bio-methane to win acceptance on a European level. Nevertheless, if an existing strong actor or network would enter the bio-methane sector, it could lead the way for institutional changes, new policy incentives and increased legitimacy for bio-methane as vehicle fuel on a European level.

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Philip Eriksson Martin Olsson

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1 Introduction

This chapter starts with the background to the Master's thesis and an introduction to the current biogas situation in Europe. This is followed by a presentation of the purpose, research questions and the delimitations of the master thesis.

1.1 Background

Transportation relies heavily on oil. In very few countries in the world does oil account for less than 97 % of the fuels used for transportation (Fulton, 2004). A number of inherit disadvantages of this dependence have over the years become more evident. The most serious drawbacks involve oil scarcity, security and negative environmental implications.

Being a finite resource, the price on crude oil will rise due to increasing demand, much supported by the rapid economic development in Asian countries like China and India. In order to meet demand, the world's oil production peak is likely to be reached in the near future. Estimates suggest that the peak will be encountered between 2010 and 2035 (May, 2004) while the International Energy Agency (IEA) expects that supplies will adequately meet demand until 2030, however requiring extensive oil production investments.

In addition to considerable production capacity investments, European countries will in the future become more dependent on few oil producers, such as Russia and Middle East countries for oil supplies (Fulton, 2004). Currently, about half of OECD-Europe's[1] oil demand is supplied through imports, but the dependence on imports is expected to grow to a level of 85 % by 2030 (IEA, 2003). Due to the internal political instability among oil producing countries and their sometimes frosty foreign relationships with Europe, the issue of fuel security have become a greater worry on the European political agenda.

Fossil fuels like oil do also imply serious environmental consequences. Especially serious is the issue of accumulating concentrations of atmospheric CO_2 which most researchers by now agree on implies greenhouse effects and climate changes. A very large share of the CO_2 released in

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[1] OECD- Europe includes: EU 15 plus Czech Republic, Hungary, Iceland, Norway, Poland, Slovak Republic, Switzerland and Turkey.

Europe can be derived from gasoline or diesel fuelled vehicles. As a matter of fact, the transportation sector within the OECD-Europe account for one fourth of the region's total CO_2 emissions and its share is expected to grow (Fulton, 2004). As a result, increasing CO_2 concentrations are expected to lead to a warmer global climate, resulting in higher sea levels and severe consequences for ecological systems, including human beings.

In response to these drawbacks – i.e. fuel security, scarcity and increasing environmental pressure – the European Union (EU) is striving to find suitable fuel alternatives that are more environmentally friendly and are produced from abundant resources within the Union. A wide set of promising fuel technologies are in the test phase but still require many years of development. The alternatives that are considered to be valid for relaxing the transportation sector's oil dependence in the near term are natural gas and the first generation of bio-fuels which includes ethanol, bio-diesel and bio-methane. As a consequence, an interest and support for these alternatives, especially bio-fuels, has emerged and is growing stronger within the EU, among European governments, companies and researchers (European Commission, 2005a; Fulton, 2004). The unifying aspect of bio-fuels is that they are all produced from biomass, such as biodegradable agricultural products and residues.

Bio-methane is equivalent to methane or natural gas, but produced from renewable resources. Biogas is the methane rich gas that develops when dedicated micro-organisms decompose organic materials in an oxygen free environment and which can be cleaned or upgraded to bio-methane, meaning natural gas quality and used as vehicle fuel (Bomb et al., 2007). The reason why bio-methane is a particularly interesting fuel alternative from an environmental perspective is because biogas is an environmentally hazardous by-product to traditional waste treatment methods such as landfilling of organic waste. When released to the atmosphere, biogas has severe negative environmental effects since methane is a greenhouse gas that is about 20 times as aggressive as CO_2. A way to avoid biogas emissions at landfill sites is to flare the gas off in stacks. An alternative method is to upgrade the biogas to bio-methane quality, use it as a vehicle fuel and thus decrease the impact of two sources of greenhouse gas emissions.

Concerning fuel security, bio-methane also display positive features since it can be produced within Europe's boarders from a wide range of feedstocks including municipal organic waste, sewage sludge, agricultural residues and energy crops. Although bio-methane can be produced from a wide set of feedstocks, the current European production is limited and do not represent the potential of bio-methane and to which extent it can replace oil as a fuel for vehicles.

1.2 Purpose

Although many estimations of the bio-methane potential previously have been done, there is a gap in research regarding current production volumes of biogas in Europe and the corresponding potential of bio-methane as vehicle fuel. *Therefore, this thesis' primary aim is to determine how much biogas that is produced within Europe at present and estimate how the biogas production may develop until 2015.*

The current and future European biogas production can be translated to a European potential for using bio-methane as fuel for vehicles. The secondary purpose of this thesis is therefore to analyze the potential of bio-methane and *identify some of the factors which are likely to decide whether this potential will be realized or not.*

1.3 Research Questions

In accordance to the primary purpose – the search for determining the current and future European biogas production – the following research questions will be addressed for a selected group of European countries.

- How has the primary biogas production developed over the last five years?
- How much biogas is currently produced?
- What is a reasonable estimate for biogas production in 2015?
- How do current policies influence biogas production and usage?

Since the secondary purpose is of more tentative nature, the following research questions will be addressed concerning the European bio-methane fuel potential.

- What are the driving forces for a realisation of the bio-methane potential?
- What are the blocking factors for a realisation of the bio-methane potential?
- Is bio-methane supported by strong actors, networks and lobby organizations?

1.4 Delimitations

The differences between the many countries in Europe are vast concerning the production of biogas. Policies, infrastructure and the economic conditions are examples of factors that differ, which results in different situations for the biogas industry. Therefore, and due to a limited time frame, this thesis will not describe all European countries in detail. Instead, the focus has been to give a general overview of possible paths that the biogas development may take based on generalised assumptions, and thereby give an overall estimation of the biogas production in Europe 2015. Since the biogas industry in Europe is not well organised or developed, even the gathering of the most basic information has been time consuming and complicated. This concerns even simple data such as the number of plants in each European country and the volumes of biogas currently produced. This is also a factor that has made detailed analyses of each individual country impossible.

2 Background to alternative fuels

This chapter will introduce the targets and goals that have been set within the European Union for alternative fuel substitution. Thereafter, a short description of the alternative fuels natural gas, bio-diesel and ethanol will be given, as well as a more detailed background to bio-methane.

2.1 Alternative fuel targets

According to EU's White Paper on transport policy, the most promising alternative fuels are bio-fuels in the short and medium term and natural gas in the medium and long term (European Commission, 2001a). With these fuel alternatives in consideration, a proposal for an alternative fuel directive was made by the European Commission in 2001 that suggested that bio-fuels and natural gas each could replace 5 % of the regions oil consumption for transportation (European Commission, 2001b). In 2003, the EU established a bio-fuel directive with the target of replacing 5.75 % of diesel and petrol put on the transport market with bio-fuels by 2010 (European Commission, 2003b). The individual member countries have been given the freedom to decide how this target should be reached with respect to which bio-fuels to prioritize and if bio-fuels ought to be blended with traditional fuels or not. Domestic targets and policies have therefore been implemented in order to stimulate the growth of the bio-fuel markets.

The target of 5.75 % substitution by 2010 is, however, no final goal. A proposal for new directives with the higher target of 10 % bio-fuel substitution by 2020 has recently been put forth (European Commission, 2007a). In addition, long term targets of replacing 20 % of conventional fuels with substitutes between 2020 and 2030 have previously been declared in the European Union's Green Paper on security of energy supplies (European Commission, 2001c).

2.2 Different types of alternative fuels

Alternative fuels can be defined as all alternatives to conventional fuels, i.e. petrol and diesel. Examples of alternative fuels are hydrogen, natural gas and bio-fuels. In turn, bio-fuels are according to the European Commission's definition, liquid and gaseous fuels for transportation which are produced from biomass (European Commission, 2003b). Biomass includes biodegradable agricultural and forestry products, residues or waste as well as biodegradable fractions of industrial and municipal waste (European Commission, 2003a). Examples of possible bio-fuels are bio-diesel, bio-ethanol, ETBE (ethyl-tertio-butyl-ether), bio-methane/biogas, bio-methanol, bio-dimethylether and bio-oils (European Commission, 2001d). However, in this report, only the alternative fuels that are interesting alternatives in a ten years time frame will be presented – i.e. bio-diesel, bio-ethanol, natural gas and bio-methane. A more comprehensive presentation of bio-methane will be given, since it is the main focus of this report. A presentation of the production figurers of alternative fuels in the European countries is given in Appendix A.

2.2.1 Bio-ethanol

Bio-ethanol, which is normally produced from wheat, corn or sugar beets, is a liquid bio-fuel. This is an advantage since they can be blended with conventional fuels and thereby do not require substantial infrastructure investments. Most cars in the EU can technically run on a blend of fuel of ethanol up to 15 %. According to the European Commission, this makes bio-ethanol together with bio-diesel the most important bio-fuel for reaching the goals set for the replacement of diesel and petrol (European Commission, 2007a). The bio-ethanol yield from one hectare of land is 5 724 litres of bio-ethanol[2], which corresponds to 2.9 toe[3] (tons of oil equivalent) (Pimentel and Patzek, 2005; The Energy Systems Research Unit, 2006b)

2.2.2 Bio-diesel

Bio-diesel is a liquid bio-fuel normally produced from oleaginous plants, such as sunflower and rapeseed (European Commission, 2007a). The fact that bio-diesel is liquid is an advantage since it can be blended with conventional diesel and use the same infrastructure, just as for bio-ethanol.

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[2] This is when sugar beets are used for the production of bio-ethanol. However, it is normally necessary to alternate the type of crop used on the same hectare of land because of various biological reasons. The calculation uses the yield of sugar beets grown in the UK

[3] 2.9 toe is equivalent to the average gas consumtion by one bus used for public transporation in Gothenburg for 40 days.

The bio-diesel yield from one hectare of land is 1 323 litres of bio-diesel,[4] which corresponds to 1.1 toe[5] (The Energy Systems Research Unit, 2006a).

2.2.3 Natural gas

Natural gas is a relatively low cost fuel alternative that can be used in compressed form (CNG) or liquid form (LNG) to run vehicles. In the southern parts of Europe, natural gas have won market acceptance as a fuel, especially in Italy that has natural gas fleet of about 402 000 vehicles (Boisen, 2006b). However, it is most often seen upon as intermediary fuel solution since it is a fossil fuel attached with similar fuel security and CO_2-issues as conventional fuels (IEA, 2003). Nevertheless, natural gas produces less CO_2, about 20 % reduction compared with conventional fuels, and does not require major modifications of conventional engine technology. For more wide spread usage in Europe, large infrastructural investments are needed since blending natural gas, CNG or LNG, with conventional fuels is not possible.

2.3 Bio-methane as an alternative fuel

Bio-methane is produced through digestion of organic waste or agricultural crops. Chemically, bio-methane is practically identical to natural gas but produced from renewable resources. Being a gaseous fuel, bio-methane can not be blended with conventional fuels but with natural gas. Using a combination of bio-methane and natural gas is a way of guaranteeing the supply of methane gas used for transportation since the production of bio-methane alone sometimes does not meet the demand.

Several cities in Europe use bio-methane as a transportation fuel for busses in the public transportation system. Examples of municipalities using refuse collection trucks, running on bio-methane also exist. However, there are important differences between the European countries in their use of biogas and bio-methane. For example, in Sweden, 30 different upgrading plants exist for up-

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[4] This is when oilseed rape grown in the UK is used for the extraction of oil.

[5] 1.1 toe is equivalent to the average gas consumtion by one bus used for public transporation in Gothenburg for 15 days.

grading biogas into bio-methane (Jönsson, 2006), whereas in France only one plant in Lille is in operation and in most other European countries no upgrading plants exist at all.

The use of bio-methane as a vehicle fuel instead of conventional fossil fuels has several environmental benefits. Since the content of carbon in bio-methane comes from nature's own photosynthesis, the combustion of bio-methane does not contribute to the net addition of greenhouse gases (Persson, 2003). Besides the reduction of the greenhouse gases, the emissions of nitrogen oxides (NO_x), hydrocarbons and particles are less for bio-methane compared with conventional fuels (Börjesson and Berglund, 2006). Bio-methane has also the advantage of being able to be produced from a great variety of feedstocks that are available in Europe. This is an important feature in relation to Europe's ambition to reduce its dependency on imports of fossil fuels. Another advantage of using engines running on bio-methane is that they are less noisy compared to engines running on diesel or petrol. This is a great advantage for busses and trucks serving urban areas.

2.4 Technologies for the production of biogas and bio-methane

Biogas is produced when specialized microorganisms decompose organic material in an oxygen free environment (Berglund, 2006). This is done at landfills, sewage waste stations and Anaerobic Digestions plants (AD-plants). Biogas can also be produced through the thermal gasification of organic materials (Jönsson et al., 2002). However, such technologies are still in the development phase and not yet commercially used for biogas production. Depending on the type of feedstock and type of plant used for the production of biogas, the methane content of the biogas varies, as demonstrated by table 2.1. It can be observed that the methane content is the lowest in the gas extracted from landfills and that the concentration of nitrogen is the highest. Both these features complicate the upgrade of the gas into bio-methane. On the other hand, centralised AD-plants have the best biogas yield and gas quality, which makes the gas the most suitable for upgrade to bio-methane and used as a vehicle fuel.

Component	Entity	Centralised AD-plant	Sewage waste station	Landfill
Methane, CH_4	vol-%	60-70	55-65	45-55
Carbon dioxide, CO_2	vol-%	30-40	35-45	30-40
Nitrogen, N_2	vol-%	< 1	< 1	5-15
Dihydrogen sulphide, N_2S	ppm	10-2000	10-40	50-300

Table 2-1: Overview of content of the biogas produced at different types of plants. Adapted from Persson (2003, page 4).

The quality and amount of gas produced at the plants listed in table 2-1 above also depends on the type of feedstock, which is presented in Table 2-2. Grease separator sludge, which generally refers to grease from slaughterhouses, has by far the highest biogas yield even though it is more mechanically complicated to digest grease than for example ley crops. The different feedstocks presented in Table 2-2 are therefore often mixed in order to facilitate the operation of the digester. It is also interesting to observe that the biogas yield from Municipal Solid Waste (MSW) is lower at landfills than when digested at an AD-plant. This illustrates the fact that the processes developed for AD-plants are much more effective compared with the anaerobic digestion processes that takes place rather uncontrolled at open air landfills.

Feedstock	Estimated dry matter content (%)	Biogas Yield (toe / dry tonne)
Manure – cow	8	0,15
Manure – pig	8	0,17
Grease separator sludge	4	0,53
Ley crops	23	0,25
Municipal Solid Waste	30	0,30
Municipal Solid Waste - Landfill	30	0,03[6]
Slaughterhouse waste	17	0,23
Tops and leaves of sugar beet	19	0,25
Straw	82	0,17

Table 2-2: Biogas yields from various feedstocks when digested at a AD-plant, if nothing else is mentioned. (Börjesson and Berglund, 2006; Themelis and Ulloa, 2005)

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[6] This biogas yield is obtained from 1 tonne of waste during 1 year in a Landfill. However, the production of biogas from a landfill continues for many years, but with a decreasing rate. The other feedstocks, when processed at an AD-plant, generally spend a couple of weeks in the digester.

2.4.1 Landfills

An oxygen free environment is created at landfills where organic waste together with other types of waste is deposed. Since the biogas produced at landfills can be dangerous for humans due to risk of explosions, and because methane is a 20 times more aggressive greenhouse gas than CO_2, there are EU directives that state that the gas should be captured at the landfills and then flared or valorised as heat or power. However, not all landfills are suitable for the collection and valorisation of biogas, depending on how the waste is disposed and compressed (Willumsen, 2006).

2.4.2 Sewage waste stations

At sewage waste stations the sludge needs to be treated and sludge digestion is one such option that also reduce the volume of the sludge. Consequently, biogas is produced that could be used for energy purposes such as heating for the plant or upgraded to bio-methane.

2.4.3 Anaerobic Digestion plants

Municipal organic waste, food industry residues, animal manure and energy crops are all feedstocks that can be co-digested or digested separately to biogas at AD plants. This can be done at either small decentralized farm scale plants or larger centralized plants. Since larger volumes are digested at centralized plants they also produce larger amounts of biogas and are therefore also more suitable for upgrading of biogas to bio-methane, which requires certain volumes of gas due to the investment costs of upgrading technology.

2.4.4 Biogas upgrading technologies

There are various techniques that can be used for the upgrade of biogas into bio-methane. The main step in the upgrading is the separation of the carbon dioxide from the methane gas (Jönsson, 2003). The technologies normally used for this will now be presented.

Pressure Swing Adsorption (PSA)

PSA is a technology that uses the adsorption and desorption characteristics of minerals or activated coal at different pressure levels, which helps remove the carbon dioxide from the methane gas. This technology is together with the water scrubber technology the most frequently used (Jönsson, 2003).

Scrubber technologies

The scrubber technologies utilize the fact that carbon dioxide is soluble in certain fluids at lower pressures than methane. (Persson, 2003) Normally, water is used as substance for the absorption.[7]

Chemical absorbtion

This technology uses chemical reactions to remove unwanted compounds from the biogas. The great advantage with this technology is that the added chemicals react selectively with carbon dioxide, which implies that no methane gas is lost in the process. However, the process is regarded as energy intensive. (Persson, 2003)

Membrane separation

Membrane separation is the least expensive technology for the separation of carbon dioxide from the methane gas. However, it is difficult to get a methane gas content of above 75 % using this technology, which makes the gas inappropriate to be used as a transportation fuel (Willumsen, 2006).

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[7] A dimethyl derivative of polyethylene glycol is sometimes used instead of water. (Persson, 2003)

3 Analytical framework for emerging technologies

This chapter will outline the theoretical framework later to be used for the analysis of bio- methane diffusion and its potential as a vehicle fuel. Diffusion of renewable energy technologies have previously been analyzed in research articles like Bergek et al. (2006a), Negro et al. (2005), Raven and Geels (2006) and Jacobsson and Lauber (2006). This thesis will follow their path and build upon this framework. Nevertheless, emerging technologies and their impact on existing technological structures as well as their role of creating new markets have been studied from many other perspectives. In order to follow the path from a technological breakthrough to successful commercialization, the point of departure for explaining the framework will be in the creation of new technology; namely innovation.

3.1 Innovation

Innovation relies heavily on two fundamentals – technology and markets. According to the linear model of innovation, see Figure 3-1, proposed by Bush, knowledge originates from basic research (Bush, 1945). The knowledge can in turn be used to bring about novel technology that can enable the creation of new or enhanced products through a process of technology push.

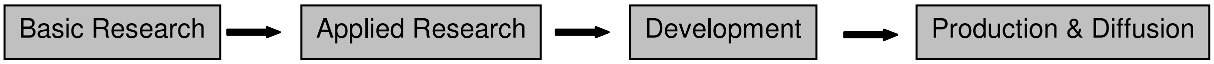

Figure 3-1: The linear model of innovation (Bush, 1945).

On the contrary, the theory of demand-pull suggests that research, and thereby also technology development, is driven by end user demands (Schmookler, 1966). That means that entrepreneurial firms first of all look at the market side and what is wanted from a customer perspective for guidance of technology and product development.

Figure 3-2: Illustration of demand-pull theory (Schmookler, 1966).

Both viewpoints are acknowledged by Kline and Rosenberg through the statement *“We must recognize not only that innovation draws on science but also that the demands of innovation often force the creation of science.”* even though they claim that *“…the notion of that innovation is initiated by research is wrong most of the time.”* (Kline and Rosenberg, 1986, p. 287). Either way, they oppose the notion that innovation can be described in a strict linear fashion, since the process of innovation is complicated and needs to be tackled in a non linear and recursive fashion. Instead, they propose a recursive chain-linked model of innovation, where feed-back loops from research, known science and the different stages of the innovation process are the central elements (Kline and Rosenberg, 1986). See Figure 3-3 below for an illustration of the chain-linked model.

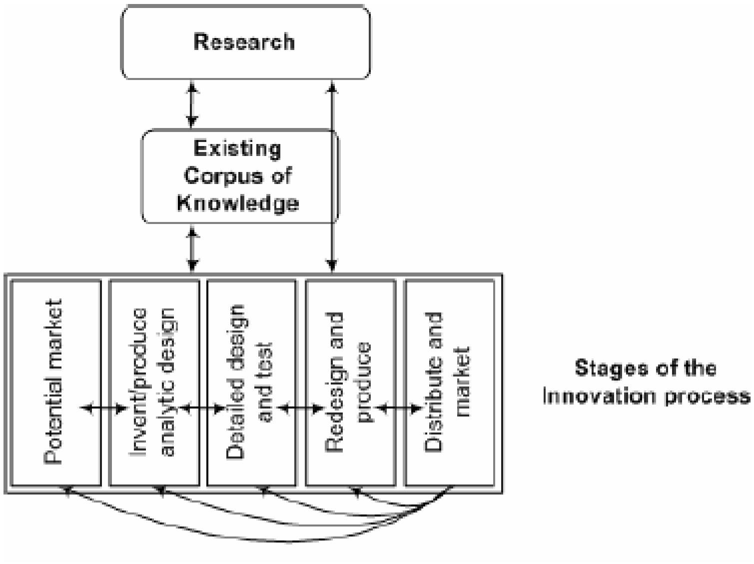

Figure 3-3: The chain-linked model of innovation, adapted from Kline and Rosenberg (1986).

It is proposed that these feed-back loops are central for overcoming or managing barriers, like uncertainty, development costs and organizational resistance for successful innovation. On the topic of organizational resistance it is said that *“...the operating systems of concern in innovation are not purely technical in nature; they are rather strongly intertwined combinations of the social and the technical.”* (Kline and Rosenberg, 1986, p. 278). Thereby, Kline and Rosenberg touch upon barriers for change that can be linked to the social context or the “socio- technical systems” of innovation (Kline and Rosenberg, 1986).

3.2 Technological Innovation Systems (TIS)

Social and societal aspects are to a greater extent emphasized in the context of technological innovation systems (TIS) which focuses on the development and diffusion of a particular technology through joint efforts rather than from a single firm perspective. Consequently, a broader stance to innovation is taken and looked upon from a meso rather than a firm perspective. Thereby the entrepreneurial firm is seen as one of the actors in a "*…network or networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate diffuse and utilize technology.*", which is the definition of TIS given by (Carlsson and Stankiewicz, 1991). The boundaries of such a system could be technologically and/or geographically defined. The constituting elements of a TIS can thereby be ascribed as actors, networks and institutions that aid a technology through a first and formative phase in order to reach a growth and finally maturity phase. See figure 3-4 below for illustration of a TIS's constituting elements.

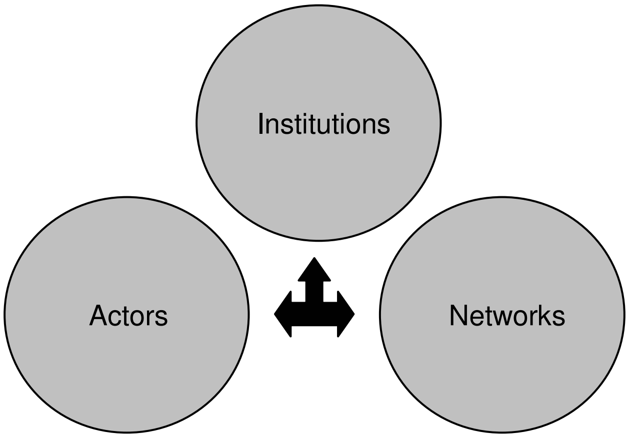

Figure 3-4: Illustration of a TIS setup.

3.2.1 Actors

As already mentioned, an entrepreneurial firm trying to profit from a specific technology can be categorized as an actor within a TIS. However, so can all other firms throughout the entire supply chain of that particular technological trajectory (Dosi, 1982). Additionally, organizations such as universities, government bodies, and non governmental organizations belong to the category of actors (Bergek et al., 2006a). For example, the Swedish TIS of biogas includes actors such as recycling companies, digestion technology suppliers, power suppliers and automotive manufactures.

3.2.2 Networks

In order to strengthen knowledge creation and diffusion and the political power of the TIS, networks are created. Networks can be seen as the interface between different actors since they link suppliers to users, universities with firms and NGOs to various firms and other organizations. By doing so, knowledge can be shared and spread (Bergek et al., 2006a). Other types of networks are built less on knowledge formation and sharing but more on joint political interests. Actors form networks with the purpose of influencing the political agenda in favor of specific technologies. Additionally, sharing and creating joint beliefs such as future visions are done through networking. Technology coalitions are thereby formed by actors in the spirit that their sum is greater their parts.

3.2.3 Institutions

Institutions include those legal and regulatory entities that political networks aim to influence. According to Edquist and Johnson (1997), institutions are responsible for establishing and providing the "rules of the game" for a specific technology. As a consequence, institutions also refers to norms and cultural aspects such as "ways to do business" within an industry.

3.3 Functions of the TIS

In a well functioning TIS, actors, networks and institutions together with external factors interact and jointly fulfil a set of functions in order to progress from a formative phase to a growth and finally maturity phase (Jacobsson and Bergek, 2004c). Seven different functions of a TIS have been identified through research by Bergek and Jacobsson (see Bergek et al., 2006a) and Negro and Hekkert (see Negro et al., 2005) and are listed in Figure 3-5 below.

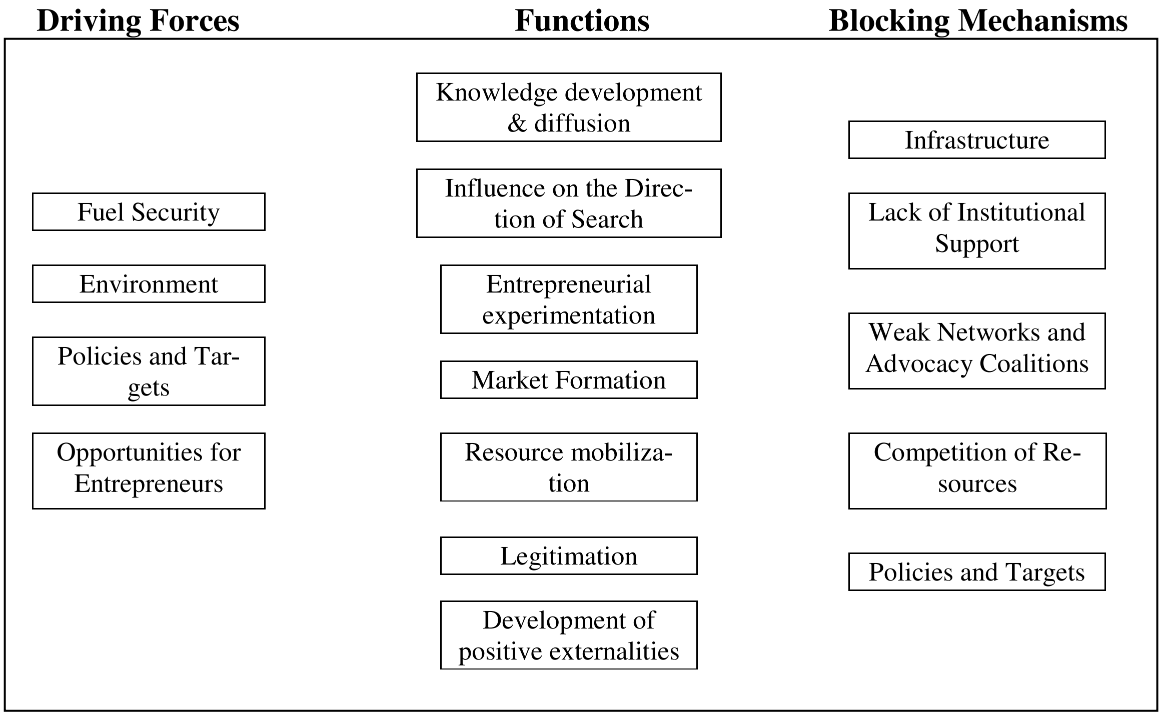

Figure 3-5: A TIS with its driving forces, functions and possible blocking mechanisms. Adapted from Bergek and Jacobsson (2004, p. 217) and Bergek et al. (2006a).

The first function in Figure 3-5, *Knowledge development and diffusion,* is an important process for the TIS to emerge, since it refers to the knowledge in the system and how this knowledge is diffused and shared within the TIS (Bergek et al., 2006a). The second function – *influence on the direction of search* – concerns the ability of the system to attract firms and other organisation to enter the system. The function also covers the ability for the system to guide the direction of search within the system (Bergek et al., 2006a). *Entrepreneurial experimentation* is important for the reduction of uncertainty in terms of technologies, applications and markets (Bergek et al., 2006a). In the early phase of a TIS, markets may not exist for the technology. Therefore, *market formation* is obviously of great importance, for example in the form of niche or nursing markets, which can lead the way to a mass market formation (Bergek et al., 2006a). *Resource mobilization* refers to both financial and human capital, and is needed for all activities within the TIS (Negro et al., 2007). *Legitimation* refers to the social acceptance and conformity with institutions affecting the TIS. This is for example needed in order to attract resources (Negro et al., 2007) and is argued to be a prerequisite for the formation of a new TIS (Bergek et al., 2006a). The last function illustrated in Figure 3-5, *Development of positive externalities,* includes the development of "free utilities" or "spill-overs" that actors can appropriate from other actors within the innovation system. These positive externalities is argued to be central to the formation of clusters and industrialisation, and also for the formation of innovation systems (Bergek et al., 2006a).

The seven functions are influenced by different driving forces. Examples of possible driving forces are given in Figure 3-5. The same functions can also be hindered by various blocking mechanisms, also listed in Figure 3-5. By identifying both the blocking mechanisms and driving forces for the development of important functions, it is possible to better understand what the possibilities are for a particular TIS to emerge. Such an analysis will be conducted in Chapter 8 for the bio-methane TIS in Europe.

4 Method

This chapter will cover methodology issues, such as secondary and primary sources of data. First of all, the work procedure of this thesis will be outlined.

4.1 Work Procedure

The work process for this master thesis started with a pre-study where the literature addressing the topic of biogas and bio-fuels was reviewed. The reason for this was to establish a familiarity with the subject and to ensure that the choice of aim and research questions would be of relevance. Research questions were formed with the aim to facilitate the fulfilment of the stated purpose of the report.

Concerning the primary aim of this thesis - *to determine how much biogas that is produced within Europe at present and estimate how the biogas production may develop until 2015* – five European countries will be presented more thoroughly. Sweden, Denmark, Germany, France and the UK were chosen since they all display unique characteristics concerning their domestic development of biogas production and utilization. A further explanation of the selection of countries is also presented in Chapter 5. Remaining European countries are covered in the Appendices. Regarding the future development scenarios, a more detailed explanation on the assumption and calculations that have been made, are presented in chapter 6.1 and in Appendix B.

Regarding the secondary aim - *to identify some of the factors which are likely to decide whether the bio-methane potential as a vehicle fuel will be realized or not* - special attention has been given to those European countries that currently use bio-methane as a vehicle fuel. Those countries include Sweden and Switzerland and Germany but comparisons are also made with other European countries.

A more thorough literature review was conducted for this analysis. Literature regarding the theory of TIS, presented in (Carlsson and Stankiewicz, 1991) and further elaborated in (Carlsson and Jacobsson, 1994; Jacobsson and Lauber, 2006; Negro and Hekkert, 2006a), was reviewed. This framework has been used for the analysis of the bio-methane vehicle fuel TIS, since it has previously been used for analysing other renewable energy technologies.

4.2 Secondary data

The mapping of the biogas production in Europe started with a review of available secondary data sources. Well-recognized journals like Energy Policy were browsed for relevant articles through the Science Direct database[8]. This was complemented through searches in databases like CHANS and LIBRIS for additional literature, e.g. PhD dissertations. Reports written by different interest groups, for example NGOs, have also been used. However, these organisations sometimes have hidden agendas, representing either companies wanting to promote investments and policy changes in favour of biogas or competing technologies. These sources have therefore been used with caution.

4.3 Primary data

The secondary data did not give adequate information regarding the future development of biogas in Europe. Detailed information regarding the current production of biogas at various plants in Europe was also missing. Therefore, the review of relevant secondary data sources had to be complemented through interviews with key persons within the bio-fuel, biogas, bio-methane TISs in Europe. Interviews have been conducted with eight key persons within the bio-methane TIS in Europe. Another 44 persons have been contacted, either by phone or face-to-face, in order to obtain information about the bio-fuel, biogas or bio-methane TISs. For a complete list of the interviews and contacts made, together with a list of attended conferences and fairs, see Appendix C. These contacts and interviews have been important for the assessment of the current status of the biogas and bio-methane industry in Europe. The interviews were generally organized in a semi structured way, that is, not all questions were written down in advance. This approach resulted in that much information that initially was not expected was received.

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[8] www.sciencedirect.com

5 Market analysis of the European biogas sector

In this chapter, the current biogas situation in Europe will be described. First of all, the general European biogas development, mainly based on EurObserver's Biogas Barometer, will be presented and discussed. Thereafter, each European country will be analyzed in more detail since the development patterns differ dramatically between European countries. Despite the fact that the European Union's directives applies to all members[9], waste management, waste water treatment methods, biogas production and utilization all differs from country to country within Europe due to national legislation and traditions. For this reason, it has also been easier to gather data for some countries, while it has been more difficult for others. Determining the total biogas production in Europe by identifying each biogas producing plant in every European country has proved to be impossible. However, an attempt has been made to quantify the number of biogas plants in each European country although up to date production statistics for these plants are not available.

Instead of covering all European countries, a set of countries with interesting characteristics will be presented in this chapter. First of all, the UK and Germany are included since they are, by far, the largest producers of biogas in Europe. Between the years 2000 and 2003, the lion's share of the European production depended on the UK and Germany. Since then, the production has continued to increase in these countries which have implied that the European biogas production has more than doubled between the years of 2000 and 2005. (EurObserver, 2004, 2006) As a result, the two countries together represented almost 70 % of the total biogas production in Europe (see Table 5-2).

Especially Germany has had an impressive biogas development since 2002, much due to favorable feed-in tariffs for the production of electricity from biogas. A similar scheme has recently been implemented in France which thereby potentially can experience a positive future development. Comparable conditions were also implemented in the early 1990's in Denmark but were later abolished, which makes Denmark's historical development particularly interesting. Being a small country, Denmark is not one of the largest biogas producers but on a per capita basis, they

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[9] The European Union's directives apply to all member countries. However, new entrants are generally given a certain time for the adaptation to the European Union's standards.

are one of the best performing. Table 5-1 below shows the selected countries' production of biogas per inhabitant.

Country	ktoe per million inhabitants			
	2002	2003	2004	2005
Denmark	11	15	17	17
Sweden	16	13	12	14
UK	18	21	25	30
France	3	3	3	3
Germany	8	15	16	19

Table 5-1: Biogas production per million inhabitants for the countries covered in this chapter (EurObserver, 2003, 2004, 2005, 2006).

The development in the UK has not resulted from feed in-tariffs. Instead, the obligation for the electricity suppliers to include electricity produced from renewable energy sources through a green certificate system has resulted in the utilisation of the biogas produced at the many landfills for electricity production. Finally, Sweden is a leader concerning biogas, since a larger share of the produced biogas is upgraded and used as vehicle fuel. The amount of biogas produced, number of plants and policies for the remaining European countries are presented in Appendices D, E and F, respectively.

5.1 Method discussion

The EurObserver is a French organization that was set up in 1997 and is made up by various energy engineers and experts. Its mission is to take part in the domestic energy debate and quantify the progression of renewable energy technologies. The Biogas Barometer is one of their yearly journals which is co-financed by the European Commission and intends to monitor the development of Biogas and evaluate the progression in comparison to the European Union's White paper targets for 2010 (European Commission, 1997).

On an overall basis, country statistics concerning biogas have been published by EurObserver in the Biogas Barometer since 1999. A weakness is that not so much underlying data to the Biogas Barometer's statistics has been published and the organisation sparsely presents references to its sources of information. These issues raise the question whether the Biogas Barometers statistics can be considered to be trustworthy.

The major strength of the EurObserver's statistics is that all relevant biogas deposits are included for all EU members. Nevertheless, there are some gaps in the data provided by EurObserver, but in these cases data from other sources has when possible been used to complement the EurObserver's statistics. In many countries, biogas is often associated with one particular deposit. In Sweden for example, biogas is generally associated with the gas produced at centralized AD-plants intended to be upgraded to bio-methane. Biogas produced at the Swedish sewage stations is generally not valued in an equal way. According to Owe Jönsson at SGC, this is due to the fact that biogas is only a by-product to their water purification activities (Jönsson, 2007). In Germany on the other hand, biogas normally involves agricultural plants for heat and electricity production. Consequently, national statistics is most often measured in the amount of electricity produced from biogas rather than primary production of biogas. Concerning biogas from landfills and sewage stations German statistics have proven to be harder to find.

In order to determine the accurateness of the statistics presented by the Biogas Barometer, comparisons have been made with the IEA renewable database[10]. Unfortunately, their statistics are from 2003 and not categorized according to production plants or deposits. Their statistics are slightly lower, 3.4 Mtoe compared to the 2003 Biogas Barometer figures of 3.9 MToe. The difference can mainly be described by lower production figures for Germany, France and the UK, while other countries except for Portugal display rather equal figures from both sources. Overall, both sources display much the same picture. The IEA biogas statistics, compared with the EurObserver's figures, is presented in Appendix G.

EurObserver's statistics have also been compared with statistics provided by IEA Task 37 country reports. In general, these country reports do display slightly higher figures. Especially the Austrian statistics reveal much higher biogas production compared to the ones presented by EurObserver. For other countries the differences are not that dramatic, even though Owe Jönsson, member of IEA task 37, consider EurObserver's statistics to be a bit modest (Jönsson, 2007).

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[10] http://www.iea.org/Textbase/stats/index.asp

Despite the weaknesses of the EurObserver statistics, it does give a good overview of the European biogas production. Even though their figures appear to be underestimated, they are considered as less misleading overestimated statistics. Therefore, their statistics have been chosen and provide background material for this thesis.

5.2 General market outlook for Europe

In 2005, the European biogas production reached about 5 Mtoe according to EurObserver's estimates. Their figures over the past six years suggest that biogas is a growing industry. In year 2000, the primary production of biogas reached 2.3 Mtoe. See table 5-2 below for detailed statistics concerning biogas production. In Appendix D the biogas production statistics is related to the heavy duty fuel consumption in each country. As already mentioned, a comparison can also be made with the European bio-diesel and ethanol production which can be found in Appendix A.

Country	**2000**	**2001**	**2002**	**2003**	**2004**	**2005***
UK	897	904	1076	1253	1492	1783
Germany	525	600	659	1229	1295	1594
France	167	276	302	344	207	209
Spain	101	134	168	257	295	317
Italy	143	153	155	201	336	377
Netherlands	143	161	149	109	126	126
Sweden	120	112	147	119	105	105
Portugal	7	1	76	76	5	10
Denmark	72	73	62	83	89	92
Austria	36	56	59	38	45	45
Belgium	48	45	56	42	74	74
Greece	2	33	42	32	36	36
Ireland	24	28	28	19	30	35
Finland	17	18	18	16	27	27
Luxemburg	2	2	2	4	5	7
Poland	-	-	63	35	45	51
Slovenia	-	-	-	6	7	7
Slovakia	-	-	-	3	6	6
Hungary	-	-	-	2	4	4
Czech Rep.	-	-	-	41	50	56
Total:	2304	2596	3062	3909	4279	4961

Table 5-2 Primary biogas production for each European country in Mtoe (EurObserver, 2002, 2003, 2004, 2005, 2006).

This increase has been possible due to two reasons – the construction of new biogas production plants throughout Europe and the expansion of the European Union. In 2002, about 3 000 plants could be found in Europe but by today this figure has increased to more than 4 000. (EurObserver, 2003, 2006) However, the progress has not been equally distributed among the countries of Europe. Despite good progression during some years, France has for example in 2005 fallen to fifth place in Europe in terms of biogas production. At the same time, the UK have doubled their production, while Germany have tripled theirs making them responsible for almost the entire increase in Europe. The second explanation, with more countries having joined the European Union has implied higher production statistics since these countries were not included in the EuroObserver's earlier data collection. However, their contribution to the total increase of biogas production have been marginal compared with Germany's and the UK's efforts.

Although the primary biogas production has developed in a positive way, far from the entire production is actually used for energy purposes. According to EurObserver, about half of the biogas produced in 2002 was flared off. No such statement were made in their last report and in 2004 it was argued that a bit more that half of the produced biogas was used, indicating a positive trend (EurObserver, 2003, 2006).

In general terms it can be said that both biogas production and utilization depends upon the domestic legislation in the European countries. The countries where the development has been most substantial have also encouraged this development through for example the EEG-law[11] in Germany and the ROCs[12] in the UK (see Appendix H for a detailed presentation of EEG). In these countries, as well as the old members (EU15), the focus of valorization have been on producing electricity unlike the eastern part of Europe where heat valorization is more dominant, with a few exceptions.

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[11] The EEG law sets the basic conditions on which the feed-in tariffs for electricity produced from electricity are based.

[12] Renewable Obligation Certificate (ROC) is the name of the certificates that the electricity distributors need to acquire, which in turn promotes the production of electricity from RES.

5.2.1 Biogas production in Sweden

The amount of produced biogas has remained fairly constant over the last years in Sweden. 2005's total production of crude biogas was estimated to 105 ktoe by EurObserver (EurObserver, 2006), which corresponds to about 8 % of the country's heavy duty vehicle fuel consumption. Following EurObserver's statistics back to 2001, the Swedish biogas production has had a rather negative development after the peak production years of 2002 and 2003 where the production reached 140 ktoe. One reason to this is that biogas produced at centralized AD-plants and farm scale plants have been totally left out by EurObserver in 2004 and 2005 which has been the growing segment of biogas production over the last ten years. Therefore, an additional 10 ktoe biogas, which is produced in Swedish centralized biogas plants (Avfall Sverige, 2006b), has been added to the EurObsever's statistics presented in Figure 5-1 below.

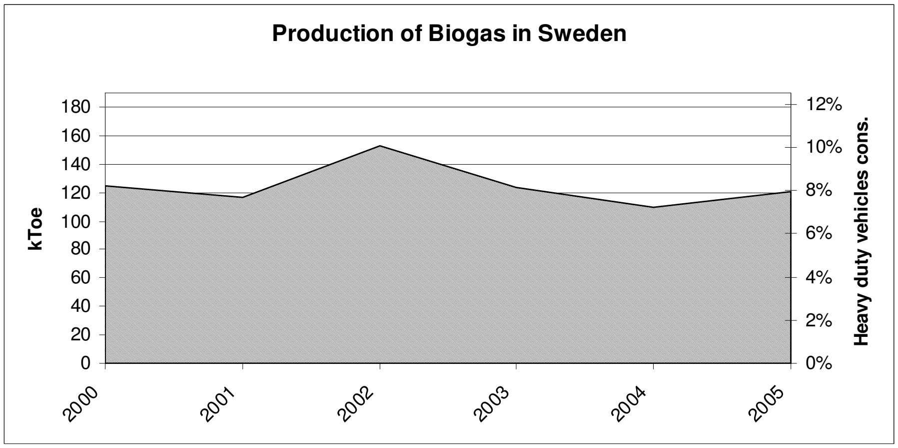

Figure 5-1: Production of biogas in Sweden between 2000 and 2005 (EurObserver, 2002, 2003, 2004, 2005, 2006)

The amount of landfill gas have most certainly decreased the last five years in Sweden, as a consequence of the legislation that introduced a ban of sorted organic waste to be land filled in 2002 which was expanded to include all organic waste by 2005 (Naturvårdsverket, 2006a). Sweden does in some aspects differ from other European countries regarding biogas production and utilization. First of all, Sweden is the only European country where sewage purification plants are the dominant source of biogas. Secondly, Sweden is the leading country concerning biogas upgrading to bio-methane as vehicle fuel. About 10 % of the produced biogas is upgraded to vehicle fuel which is the most favourable utilization alternative in Sweden since the current market price of bio-methane is approximately 20- 30% lower than petrol on energy basis (Lantz et al., 2007)

5.2.1.1 Number and type of biogas plants

The largest share of the biogas production in Sweden takes place in water sewage stations. According to the Swedish Biogas Association 134 Swedish sewage purification plants digested sludge and produced biogas by 2001 and the biogas production from these plants was measured in 2001 to be 810 GWh (69 ktoe) which is well in line with the EurObserver's sewage gas estimation of 69.3 ktoe for 2005 (Berglund, 2006; EurObserver, 2006; Svenska Biogasföreningen, 2006). However, despite being the biggest biogas deposit in 2001, no newer statistics for this deposit have been found. This can be explained by the fact that sewage stations do not see the production of biogas as one of their main purposes, which is demonstrated by their lack of corporation with the Swedish biogas association (Svensson, 2006).

The fastest growing segment of biogas production technology is however centralized AD plants that digest organic waste. Currently, 15 centralized AD plants that produce biogas from municipal waste exist in Sweden. In year 2004, the centralized AD plants treated 10 % of the Swedish municipal waste and generated crude biogas of about 119 000 MWh or 10.2 ktoe (Avfall Sverige, 2006b).

Even if organic waste is not allowed to be landfilled in Sweden any longer due to the national ban on landfilling organic waste in 2005 (Avfall Sverige, 2006c; Svenskt Avfall, 2007), landfills still exists. Over the last ten years the number of landfill sites has declined from about 300 to 150. Landfill gas is collected at 72 landfill sites and 57 landfills reported to use the gas for the production of energy in 2003. At the remaining 15 sites the landfill gas was primarily flared off (RVF, 2003). According to EurObserver's statistics, Swedish landfill gas amounted to 35.8 ktoe in 2005 (EurObserver, 2006). A slightly higher figure of 38 kToe was given in 2003, which could be a possibly sign of declining biogas extraction rate in Swedish landfills (RVF, 2003). With a national target set that 35 % of Swedish food-waste should be organically treated by 2010 (Avfall Sverige, 2006c), it is however likely that a larger fraction of organic waste will be digested in biogas plants in the future, which will compensated for this decline. The number of biogas plants in Sweden and corresponding production amount according to EuroObserver, and the additional

10.2 ktoe from centralized (Avfall Sverige, 2006a) and 0.5 ktoe from farmscale plants (Berglund, 2006), is shown in Table 5-3.

Type of biogas plant	Number of plants	Production ktoe
Landfill plants	72 [1]	35.8 [5]
Municipal waste water treatment plants	134 [2]	69.3 [5]
Industrial waste water plants	-	
Centralized biogas plants, co-digestion	15 [3]	10.7 [6&7]
Farm scale plants	6 [4]	
Total	231	115.8

Table 5-3: Number of Swedish biogas plants in 2006 and corresponding production volumes. Sources: 1. (RVF, 2003); 2. (SBGF, 2007); 3. (Avfall Sverige, 2006a); 4. (EADN, 2007); 5 (EurObserver, 2006); 6.(Avfall Sverige, 2006b); 7. (Berglund, 2006).

Finally, a marginal amount of biogas is also produced at agricultural biogas plants throughout Sweden. During the last 30 years, 23 farm scale biogas plants have been in use. However, some of these plants are no longer in operation. Eight plants where reported to still be in operation in 2003 (Gustavsson and Ellegård, 2004) but by 2005 two more had been closed down (EADN, 2007). The contribution to the total Swedish biogas production from these plants is supposed to be only 0.5 ktoe (Berglund, 2006).

5.2.1.2 Biogas utilization

It is especially municipal transportations that have made the transition to use biogas as fuel. According to a study by the Swedish Environmental Institute, between 600 and 800 busses for municipal transportation were bio-methane compatible in 2005. The actual number of bio-methane buses are, however, more difficult to determine since natural gas or other fuels also can be used for these buses and the choice is dependent of the current fuel supply (Norrman et al., 2005). Waste transportation trucks as well as normal cars are also fueled with bio-methane in Sweden. As for the municipal transportations, natural gas and traditional fuels are also compatible for cars and trucks which make the actual number of vehicles running on biogas somewhat hard to quantify. However, the total annual amount of produced biogas and upgraded to bio-methane represents the average annual fuel consumption of 8 000 cars (Ahnland, 2006).

The biogas that is used for transportation is mainly produced at centralized AD plants but also at sewage purification plants. Landfill gas is mainly used to produce heat. All 57 sites that reported to valorize its gas in 2003 did it in the form of heat. At nine of these 57 sites, electricity was produced along side with heat (RVF, 2003).

It should also be noted that heat and electricity often is an alternative at centralized AD plants that mainly is focused on upgrading biogas to fuel. For all sorts of plants, the last alternative is to flare off the produced biogas, which most often occurs during summer when the demand for heat and electricity is lower.

5.2.1.3 Future outlook for biogas in Sweden

There are some ongoing biogas projects in Sweden that will have a positive effect on the production in the coming years. According to Läckeby Water Group, 4 or 5 new biogas plants will be constructed within the coming two years in Sweden (Axelsson, 2006).

The Western region of Sweden is particularly active in expanding its biogas production. The construction of a new pipe line will enable a greater amount of the biogas produced at the sewage waste station Gryaab, Gothenburg, to be upgraded in Arendal, where a new upgrading plant is being built. The upgraded biogas from Arendal is intended to be used as transportation fuel and provide 4 000 vehicles with biogas on an annual basis.

An interesting research project is also being carried out by Göteborgs Energi and the Chalmers University of Technology which deals with novel and innovative technologies for wood gasification. In full scale, such technologies could possibly produce much larger quantities of biogas, which potentially could be used to provide Rya Verken with biogas instead of natural gas or as transportation fuel. Currently, the project is still in its early phase but plans exist for building a plant next to Rya Verken, with a 100 MW capacity and annual energy production of 800 GWh (Ahnland, 2006).

The latest biogas project in the Gothenburg region however concerns building a municipal waste biogas plant. Details are still unclear, but for certain is that Business Region Göteborg has applied for 150 million SEK grants, for the construction of such a plant. Grants are provided through a program of climate investments called Klimp, and in 2006, 40 % of this program's money will be invested in Swedish biogas projects (Ahnland, 2006).

Katrineholm is the Swedish city that so far has been granted the most money in 2006. 80 million SEK will finance a new plant for digesting sewage waste sludge to biogas. This would however only cover the first out of three steps of the city's planned biogas investments. In the next phase, co-digestion with manure and energy crops is planned. Primarily, manure from the food company Kronfågel which currently is transported to Denmark for digestion would instead be digested in Katrineholm in the second step (Ahnland, 2006).

Another city that has been rewarded Klimp grants is Helsingborg that will use the money to extend its current biogas plant in order to double its biogas production capacity. Stockholm and Varberg are other cities where discussions and plans are being made for building biogas plants (Axelsson, 2006). There are several other cities were discussions regarding new AD plants has been held for many years, but where concrete actions and decisions regarding the construction has not been taken.

5.2.2 Biogas production in Denmark

Like Sweden, Denmark is not one of the largest producers of biogas in Europe but in relation to its size it is one of the most developed biogas nations. Distinguishing for Denmark is small scale and centralized CHP plants that digest agricultural residues, primarily animal manures.

In 2005, Denmark produced in total 92.3 ktoe biogas (EurObserver, 2006). Small scale agricultural and larger centralized biogas plants are the major contributors with a production share of more than 60 %. The input from landfill gas only accounts for 15 % of the biogas production, which is the lowest share in Western Europe (EurObserver, 2006). The production of primary biogas in Denmark between 2000 and 2005 is illustrated by figure 5-2 below.

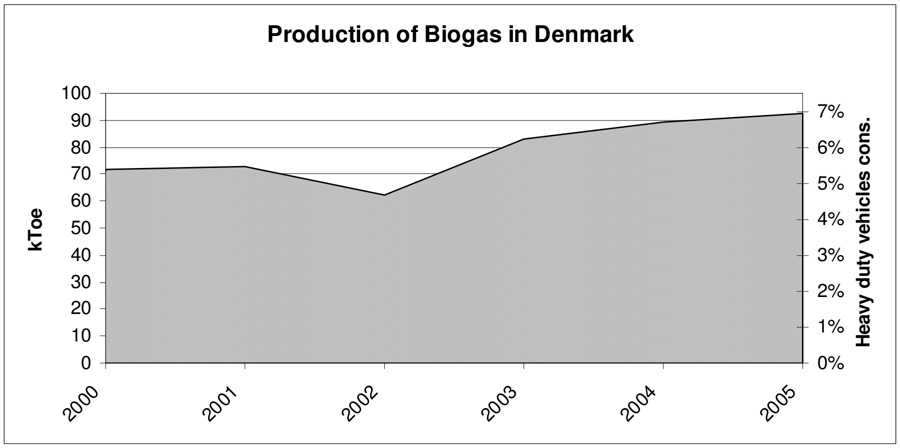

Figure 5-2: Production of biogas in Denmark between 2000 and 2005 (EurObserver, 2002, 2003, 2004, 2005, 2006).

5.2.2.1 Number and types of biogas plants

Denmark has been somewhat of a pioneer concerning biogas and started early to invest in the technology. The largest contribution to Denmark's primary biogas production comes from its centralised biogas plants. Currently, 20 large scale biogas plants and 60 farm scale plants exist in Denmark (Holm-Nielsen and Seadi, 2006), but unfortunately, plant production statistics are only available for 31 of the 60 farm scale plants (Dansk Bioenergi, 2006). The increase in farm scale biogas plants has also been confirmed by the Danish Biogas Branch organization and by research performed by Raven (Hoegh, 2005; Raven and Geels, 2006).

All wastewater treating facilities in Denmark uses anaerobic digestion for the stabilization and volume reduction of the sludge (Danish Ministry of the Environment, 2006). Consequently, a bit more than 20 % of the Danish biogas is produced at these facilities. In 1997, statistics from Holm-Nielsen revealed that 64 sewage waste plants produced biogas (Holm-Nielsen and AI Seadi, 1997). By 2003, this number was unchanged indicating that all sewage waste plants already have been equipped with biogas digestion technology. An additional 5 industrial waste water plants do however exist (Holm-Nielsen and Seadi, 2006).

According to landfill consultant Hans C. Willumsen's research, Denmark possessed 21 gas extracting landfills in 2001 (Willumsen, 2001) . Out of these landfills, two of the these were constructed to valorize landfill gas to district heating, while nine are built with combined heat and power (CHP) technology and the rest is solely producing electricity power. In a report from 2003, another 4 Danish landfills had begun to extract gas, summing up to a total of 25 gas extracting landfills (Willumsen, 2004).

An interesting aspect of Danish landfills is that despite the fact that 15 more landfill extract gas in 2003 compared with 1997, the current gas extraction lower than 1997. In contrast, the number of sewage waste stations and centralized biogas plants has remained constant while their biogas output has increased. A possible explanation to this might be more effective technologies and greater amounts of organic waste that have been digested in these plants. The current production, that sums up to 93.5 ktoe (EurObserver, 2006), is presented in Table 5-3 below.

Type of biogas plant	Number of plants	Production (kToe)
Landfill plants	25 [1]	14.3 [4]
Wastewater treatment plants	64 [2]	20.5 [4]
Industrial waste treatment plants	5 [2]	
Centralized biogas plants, co-digestion	20 [2]	57.5 [4]
Farm scale plants	60 [3]	
Total:	**174**	92.3 [4]

Table 5-4: Biogas plants and production in Denmark in 2005. Sources: 1. (Willumsen, 2004); 2. (Holm-Nielsen and Seadi, 2006) 3. (EADN, 2005, 2007); 4. (EurObserver, 2006)

5.2.2.2 Biogas utilization

Denmark has almost exclusively CHP plants, which mean that electricity and heat is produced at almost all AD-plants. The major explanation for the focus on CHP plants is probably the feed-in tariffs for electricity production during the 1990's, which supported CHP technology.

5.2.2.3 Future Outlook of biogas in Denmark

There are currently two biogas projects that are being carried out in Denmark (Holm-Nielsen and Seadi, 2006). One of these remains in the planning phase while the other has been passed on the construction stage. The one that is being constructed is located in Foulum, a test plant that is expected to produce 0.8 ktoe annually, equivalent to providing 200 houses with electricity, and is planned to be in operation in the end of April 2007 (DIAS, 2006). The other plant will be located in Holstebro and is argued to become the world's biggest biogas plan. The plant will produce approximately 10.6 ktoe per year. The main feed-stock to be digested is animal manure, which will be provided by 200 farmers in the area. The plant is scheduled for start up in January 2009. (Maabjerg Bioenergy, 2006)

5.2.3 Biogas production in Germany

As already mentioned, Germany has been the country in Europe with the most rapid biogas production development. Figure 5-3 indicate that its primary production have tripled since year 2000. Centralized AD plants together with farm scale biogas production were the main contributors, representing 40 % of the total biogas production in 2005. Landfill gas represented the second biggest deposit with a 35 % production share, while gas from sewage sludge purification plants contributed with the remaining 25 %. However, despite its expanding biogas sector, Germany was still not the leading producer in Europe in 2005, with its primary production of about 1.6 Mtoe (EurObserver, 2006). Germany is however likely to catch up with the UK reasonably soon, if they have not already done so. The focus of attention in Germany has in particular been on small scale agricultural plants often using CHP technology.

One negative aspect of the rapid development of farm scale biogas plants in Germany is that other biogas deposits do not receive the same amount of attention. For that reason, additional sources of biogas production statistics to compare with EurObserver's have proven to be hard to find. This especially concerns sewage and landfill plants.

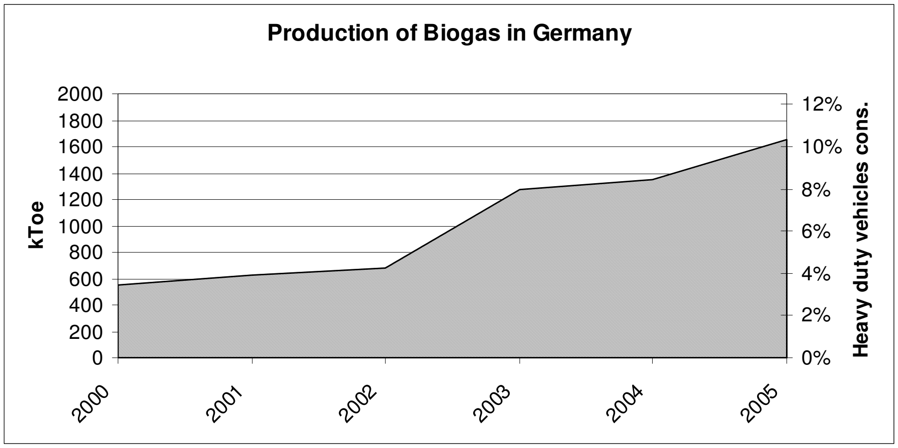

Figure 5-3: Primary biogas production development in Germany (EurObserver, 2002, 2003, 2004, 2005, 2006).

5.2.3.1 Number and type of biogas plants

In 2005, the number of farm scale plants added up to 2 700 but already by the end of 2006, 4 000 farm scale plants is expected to be in use according to the German Biogas Association's managing director (Gomez, 2006b). Peter Weiland's statement – *"50 new biogas plants are built every month in Germany"* gives an indication of the rapid development in Germany (Weiland, 2006). The size and capacity of these biogas plants have also grown since energy crops to a larger extent is being digested in these plants (Tentscher, 2007).

Even if it is a fine line between farm scale and centralized biogas plants in Germany, 52 centralized plants was in operation in 2002, treating 2 500 tons of bio-waste per year or more (IEA Task 37, 2006). The centralized and farm scale plants with relatively equal contribution summed up to 650 ktoe in 2005 (EurObserver, 2006). However, due to rapid progress of farm scale plants this figure is inaccurate at present.

Even if Germany has been proactive with recycling and waste management, landfills are still being actively used. Between 1995 and 2005 the number of landfills receiving household waste decreased from 474 to 346 sites and this figure is expected to continue to decrease dramatically until 2009 (Landfill Online, 2006). The gas produced in these landfills is to a certain extent collected and utilised. Landfill gas consultant Hans Willumsen, who has studied gas extracting landfill sites throughout the world, claimed that 182 landfills extracted gas in Germany in 2004 (Willumsen, 2004). Landfill specific data have not been found with exception for a few Regions (Bundesländer). For that reason, no confirmation of the EurObserver's estimation that 573 ktoe of landfill gas was produced in 2005 have been made. What can be said is that German landfills must be much larger and extract more gas compared to Swedish and Danish landfills.

Sewage waste plants are also a great deposit of biogas. EurObserver reported that slightly more than 370 ktoe biogas was produced from Sewage waste plants in 2005 (EurObserver, 2006), which is by far the greatest contribution from this deposit among the countries in Europe. Even if no detailed information on a plant basis has been found, it is still a surprisingly low figure considering the great number of sewage waste plants in Germany. According to Reinhard Reifenstuhl at the German Association for Water, Wastewater and Waste approximately 10 000 sewage waste plants exist in Germany (Reifenstuhl, 2006). The lion's share of these plants are however small, too small for being able to produce biogas from an economic point of view (Tentscher, 2007). Only 925 sewage plants use anaerobic digestion for sludge treatment and approximately 500 of these plants use the biogas for electricity production but an interesting remark was made by Reifenstuhl, namely that the larger sewage waste plants generally do not use digestion technology[13] and hence do not produce biogas (Reifenstuhl, 2006). An estimation of the total number of German biogas plants is presented in the Table 5-5 below, together with the production volumes.

Type of biogas plant	Number of plants	Production ktoe
Landfill plants	182 [1]	573.2 [5]
Wastewater treatment plants	~925 [2]	369.8 [5]
Industrial waste treatment plants	-	-
Centralized biogas plants, co-digestion	52 [3]	651.4 [5]
Farm scale plants	~2 700 (4000) [4]	
Total	~3 434 – 5 159	1 594.4

Table 5-5: Number of German biogas plants and biogas production in 2006. Sources: 1.(Willumsen, 2004) 2. (Reifenstuhl, 2006) 3. (IEA Task 37, 2006)4.(Gomez, 2006a) 5. (EurObserver, 2006)

5.2.3.2 Final usage of Biogas

The production of electricity is the main mode of biogas utilization in Germany. Favorable price guarantees for electricity through the Renewable Energy Act (EEG-law) have particularly stimulated the farm scale electricity producing biogas plants. Even though electricity is prioritized, CHP technology is widely spread in all types of plants, from farm scale to landfill plants, in order to achieve higher energy yields. However, the produced heat can most often only be used for heating the biogas plant itself and much energy is therefore lost (Tentscher, 2007).

Upgrading biogas to bio-methane and using it as vehicle fuel is not particularly common in Germany. Some positive indications in this direction can nevertheless be seen. At present there are two plants in Germany that upgrade biogas and inject it to the natural gas grid and one bio-

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[13] An alternative to the use of anaerobic digestion for the stabilisation of sewage sludge is to treat the sludge with lime.

methane fueling station for vehicles have recently been opened in Jameln (Tentscher, 2007; Weiland, 2006).

5.2.3.3 Future Outlook

As previously mentioned, the German biogas sector is growing due to the rapid rate of expansion of farm scale biogas plants. The good economic conditions for producing electricity from biogas is likely to remain for many more years, but indications of using biogas for other purposes are starting to appear.

Biogas upgrading to vehicle fuel quality could potentially become more wide spread. One incentive is that bio-methane as vehicle fuel will be tax relieved until 2018 (Weiland, 2006). In line with this development is a proposal for a new law, Gaseinspeisegesetz (GEG), which will imply better compensation for biogas upgrading and natural gas net injection. Wolfgang Tentscher of the German Biogas Association is lobbying for this GEG law proposal to be enforced since it is a more efficient way of using the energy content in biogas (Tentscher, 2007), since most of the heat produced as a by-product at the farmscale biogas plants can not be used for heating purposes. In line with this proposal is the self-liability to inject 10 % bio-methane to the natural gas that is sold as vehicle fuel by 2010 (Weiland, 2006).

5.2.4 Biogas production in the UK

According to the Biogas Barometer, the UK has been the biggest biogas producer in Europe between 2000 and 2005. Landfills are the major source of biogas in the UK, which corresponded to 90 % of the total primary production in the UK, which summed up to 1780 ktoe in 2005 (EurObserver, 2006), as illustrated by Figure 5-4 below. The increased gas extraction from Landfills also represents the total biogas increase in the UK, since other deposits have remained at almost a constant level since 2000. However, less biodegradable material will be landfilled as a result of the EU Landfill Directive in the coming 10 years (see Appendix F for the EU directives). Therefore, landfill gas will probably slowly reduce in output while other waste management options will begin to play a greater role (REA, 2006c).

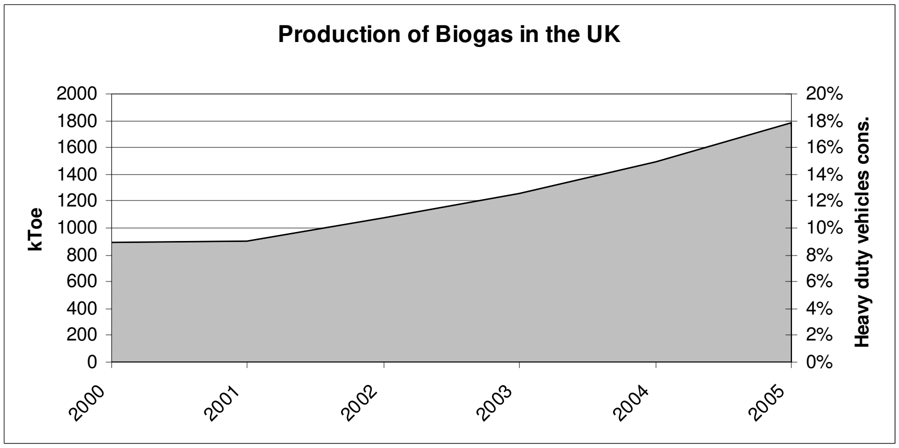

Figure 5-4: Primary Biogas production in the UK between 2000 and 2005. Sources: (EurObserver, 2002, 2003, 2004, 2005, 2006)

5.2.4.1 Number and types of biogas plants

Approximately 365 landfills in the UK collect and use biogas for the production of electricity or heat (Restats, 2006). In comparison to the approximate number of 90 sewage sludge plants, 3 farm scale and 3 centralized biogas plants it is easy to understand its dominating position (REA, 2006b). These biogas plants are listed in Table 5-6 below.

Type of biogas plant	Number of plants	Production ktoe
Landfill plants	365 [1]	1617.6[3]
Wastewater treatment plants	~ 90 [2]	165 [3]
Industrial waste treatment plants	-	
Centralized biogas plants, co-digestion	3 [2]	0 [3]
Farm scale plants	3 [2]	
Total	~3 434 – 5 159	1782.6

Table 5-6: Biogas plants in the UK and biogas production statistics. Sources 1. (Restats, 2006); 2. (REA, 2006b) and 3. (EurObserver, 2006)

5.2.4.2 Final use of biogas

Electricity is almost the exclusive mode of biogas valorization in the UK. The major reason is the Renewable Obligation Certificates (ROC) that was introduced in 2002 in order to stimulate electricity generation from renewable sources. Producing electricity from landfill gas has therefore become one of the largest renewable energy source in Britain, even though it has not been economically viable for smaller and older landfills to produce electricity rather than flare the gas (NSCA, 2006).

5.2.4.3 Future outlook

The 2006 IEA Task 37 country report concerning the UK gives a rather pessimistic view of the current and future development concerning biogas. Concerning AD plants only two facilities were opened in 2006. The first one of these is located in Leicester while the other one can be found in Shropshire. Even though these new plants have been opened, less biogas is being upgraded to bio-methane and the number of fuelling stations and bio-methane vehicles are declining (Maltin, 2006).

One underlying reason for the halting AD-plant development in the UK is that the current ROC policy, which has had a successful impact on landfill biogas extraction, does not support the construction of AD-plants. According to the Renewable Energy Association the government has not been receptive to alternative policy approaches even though the result of the ROCs has been disappointing (REA, 2006c). According to Renewable Energy Association (REA), only 4 AD-plants have been approved and will be constructed in the near future (REA, 2006a).

It is not only the development of organic waste treatment methods that have been halting. According to the landfill expert Hans C. Willumsen, the UK's resentment of waste combustion can be derived from a *"…psychological or mental barrier that waste should not be burned, rather be sent to a landfill."* (Willumsen, 2006)

Nevertheless, there are also some positive indications concerning the future development. First of all, the extraction of biogas at landfill sites for electricity production is still increasing in the UK and more landfills will be equipped with extraction systems in the near future. According to the UK Department for Trade and Industry (DTI), 50 landfill gas extraction projects have been approved and is about to be constructed. Applications for 8 additional landfill gas extraction projects are pending for approval (DTI, 2006).

5.2.5 Biogas production in France

A few years ago, France was the third biggest biogas producer in Europe despite a relatively big gap to Germany and the UK in the leading positions. However, concerning biogas, not much has happened in France the last couple of years as illustrated by Figure 5-5, and in 2005, Italy and Spain surpassed the French biogas production of 209 ktoe (EurObserver, 2006). Indications that a more positive development is likely to come, does however exist considering the new feed-in tariffs introduced in July 2006.

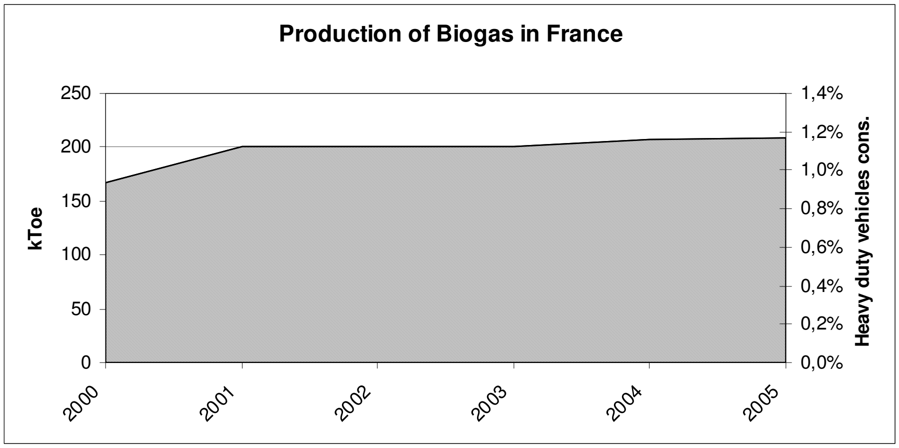

Figure 5-5: Biogas production development in France (EurObserver, 2002, 2003, 2004, 2005, 2006)

5.2.5.1 Number and type of biogas plants

Of the great number of landfills in France, 22 sites are collecting and valorising landfill gas. Landfills are therefore the primary deposit of biogas even though 83 municipal sewage purification plants and 126 industrial sewage purification plants adding up to a total of 209 plants also generate a considerable biogas input (Gaz de France and ADEME, 2005). Centralized or farm scale anaerobic digestion plants are however close to non existent in France. In 2002, 2 centralized and 7 existing farm scale biogas plants were reported (EADN, 2005; IEA Task 37, 2006). See Table 5-7 below for an overview of French biogas plants according to category.

Type of biogas plant	Number of plants	Production ktoe
Landfill plants	22 [1]	129 [4]
Municipal wastewater treatment plants	83 [1]	77 [4]
Industrial waste water treatment plants	126 [1]	
Centralized biogas plants, co-digestion	2 [2]	3 [4]
Farm scale plants	7 [3]	
Total	240	209

Table 5-7: Number of biogas plants and their biogas production. Sources: 1. (Gaz de France and ADEME, 2005); 2. (IEA Task 37, 2006); 3. (EADN, 2005) ; 4. (EurObserver, 2006)

5.2.5.2 Final usage of Biogas

In contrast to all other Western European countries, France is using its biogas in larger extent for heat rather than electricity, which the EurObserver explains with the poor conditions for producing electricity in the past. With a new law passed in 2006, that guarantees a better price for electricity generated from biogas, this situation can be expected to change.

5.2.5.3 Future Outlook

As previously mentioned, in 2006, a new law was passed concerning the compensation scheme for electricity production from biogas (Ministère de L'Economie, 2006). Hence, the economic incentives for biogas investments have been improved in France. Things are also starting to happen in France where 4 centralized biogas plants are under construction and the construction of another 14 plants is to be started in the near future (Gaz de France and ADEME, 2005; Servais, 2006). It is however unclear how much biogas these facilities will produce. Another interesting feature with the French biogas market is the fact that German biogas companies, i.e. technology suppliers, start to enter the market, which according to Dr. Wolfgang Tentscher indicates that many new AD-plants will be constructed in France in the near future (Tentscher, 2007).

6 Forecasting the European biogas production

In this chapter, three different forecasts for the biogas production until 2015 will be presented for the five countries. The forecasts for the remaining countries are presented in Appendix I and J. Before the different forecasts for the countries are presented, the method used for the forecasts will be discussed.

6.1 Forecast method

The growth of the biogas production in Europe is highly dependent on governmental policies and incentives to stimulate the use of renewable energy sources. Examples on the importance of governmental policies can be taken from Germany where the introduction of feed-in tariffs for electricity produced from biogas, through the renewable energy in year 2000 resulted in an impressive increase in the construction of new biogas plants (Negro and Hekkert, 2006b). Another example can be taken from Denmark, where the introduction in 1998 of a more market oriented price policy on the electricity produced from biogas replaced a feed-in tariff system. This has resulted in that no new centralised biogas plants have been built in Denmark since 1998. When the fixed feed-in tariff was used, one or two new centralised biogas plants were built every year (Raven and Geels, 2006).

The fact that the development of the biogas sector in Europe is highly dependent on various governmental policies makes it difficult to forecast its development. As illustrated in the paragraph above, incentives can quickly be eliminated, as in Denmark, or introduced, as in Germany, and thereby change the outlook for the industry. For this reason, we have developed three different forecasts for each country, based on different scenarios. The impact of each forecast is displayed by comparing the energy content of biogas to the diesel consumption of heavy duty vehicles in Europe. The forecasts will now be presented and motivated.

6.1.1 Planned projects

The first forecast that will be presented is based on biogas plants that are under construction today or where decisions for construction have been taken. Since it has been hard to find information regarding planned projects throughout Europe, this forecast has only been conducted for Sweden, Denmark, France and the UK. Regarding Germany, the current development is so rapid that far from all new biogas plant projects have been identified. For that reason Germany has been left out since since the available information would result in a misleading forecast.

The process of building a biogas plant generally takes about two years – from that the decision is taken until the plant is in operation (Forsberg, 2006). This means that many future plants that are unknown today could be in operation before the year of 2015. This type of prognosis will therefore probably generate an underestimation of the actual development.

The type of plants that have been included in this forecast is generally centralised AD plants. Investments in smaller farm-scale biogas plants are less known to the public and they are also producing much less biogas even though their accumulated contribution can have important effects. However, the lower volumes produced at these plants make them less interesting for bio-methane upgrading, since upgrading requires certain gas volumes to be economically viable (Tentscher, 2007). New projects at landfills and sewage plants will also be treated when information is available.

6.1.2 The Catching Up Forecast

This forecast is based on the assumption that the European countries have about the same possibilities for producing biogas per inhabitant. The Biogas Barometer’s statistics according to the deposits landfills, sewage sludge and centralized combined with farm scale plants form the basis for this forecast. Instead of using the best performers, the second best performing country of each deposit per inhabitant has been selected, and used as a basis for the other countries’ forecasts. The second best perfomer for each deposit have been chosen in order to remove outliers and thereby get less radical results. Conviently, Germany is the second best performing country per inhabitant in all three categories. Therfore, it is assumed that all other European countries will catch up with the current German per capita production of biogas within in a ten year time frame.

One weakness of this approach is the assumption of increased landfill extraction despite that fact that less organic waste will be sent to landfills in the future. Increasing biogas production at biogas plants could be argued to be at the expense of landfill biogas extraction. Therefore, it could be difficult for some countries to increase the production from both biogas plants and landfills at the same time. In countries where most landfills already have been equipped with gas extraction systems, like Denmark and Sweden, this will be an issue. For most European countries it would be possible to increase the biogas production from both deposits simultaneously, since only a small share of the existing landfills have been equipped with extraction systems. Especially this applies to eastern European countries. Despite the availability of landfills, the forecast implies a greater challenge for Eastern European countries because their per capita biogas productions volumes are at present much lower than that of Germany. For a more detailed explanation, the underlying calculations used to generate each country's forecast are presented in Appendix B.

6.1.3 The Feed-in Tariff Forecast

This forecast is based on the assumption that the European countries will implement a similar feed-in tariff based system for the pricing of energy produced from biogas as they have today in Germany. The forecast assumes that if similar policy instruments are implemented in other European countries, these countries will partially be able to catch up with Germany's production of biogas in 2015. Further on, it assumes that Germany will continue its development within the biogas sector, and the other European countries will succeed in reducing its production gap to Germany with 50 % in terms of biogas per inhabitant in 2015, compared to 2005.

For many countries, this implies an impressive yearly increase in the production of biogas. The reason why this type of forecast is interesting is that similar patterns of development have been observed in other related technology branches that currently are more developed than the biogas sector. For example, when studying the diffusion of wind power installations, an impressive catching up process by the countries that previously were considered as laggards can be identified. Under a ten year time frame, countries that had one tenth of the installed wind power capacity per inhabitant compared to the leading country were able to reduce this gap to one fifth. This is demonstrated in Table 6-1. For the year of 1995, it can be observed how Germany had about one tenth and Spain about one thirtieth of the capacity installed per inhabitant in Denmark. Ten years later, in 2005, Germany and Spain have both about one fifth of the installed capacity per inhabitant in Denmark.

		1987	1989	1991	1993	1995	1997	1999	2001	2003	2005
Denmark	Watt / inh.	21,1	48,7	76,5	91,0	114,7	209,2	328,1	473,7	577,1	578,4
	Increase	133%	131%	57%	19%	26%	82%	57%	44%	22%	0%
Germany	Watt / inh.	0,0	0,3	1,3	4,0	13,8	25,2	53,9	106,1	177,0	223,3
	Increase	200%	600%	429%	201%	240%	83%	113%	97%	67%	26%
Spain	Watt / inh.	0,0	0,1	0,5	2,8	4,0	8,3	26,0	78,6	146,4	236,9
	Increase	0%	400%	300%	500%	42%	106%	214%	203%	86%	62%

Table 6-1: The wind energy technology development in three different countries. (Bundesverband WindEnergi e.V., 2006; Energimyndigheten, 2006; European Wind Energy Association (EWEA), 2005, 2006; Grusell, 1999),

Wind power has experienced an impressive growth the last ten years and the countries that were in the forefront ten years ago have remained in the leading position even though the gap to other countries have shrunk. The wind power industry is also similar to the biogas sector in the sense that its development is strongly influenced by governmental policies, and by the fact that they are both energy technologies that are exposed to much the same type of policies and regulations.

Again, this forecast is based on the statistics from the Biogas Barometer and Germany is chosen as the targeted country to catch up. The future German biogas production has been estimated with respect to their historical development. The strong development concerning the construction of biogas plants in Germany in the last couple of years has been used as a measurement of the possible development until 2015. The construction of new biogas plants is strongly influenced by the feed-in tariffs that were introduced in 2004 (Negro and Hekkert, 2006b; Tentscher, 2007). The growth pace can be expected to declaine over the years since the guaranteed feed-in tariffs are reduced with 1.5 % annually. On the other hand, the current feed-in tariffs might be replaced or complemented by other incentives for the stimulation of the development of the biogas sector. The spot market price of electricity might also continue to increase and thereby make electricity from biogas more attractive (Tentscher, 2007). Table 6-2 illustrates the expected growth rate for biogas produced from farm-scale and centralised biogas plants and the total impact this growth has on the German biogas production. Compared to the development of wind energy technology in Germany the yearly procentatges are fairly modest. Nevertheless, displayed by its relation to the energy consumption of heavy duty vehicles in Germany indicates a sizeble growth.

Year	Growth rate (farm-scale & centralised plants)	Biogas production (kToe)	Heavy Duty Transp. Cons.
2006	30 %	1789	12%
2007	30 %	2043	13%
2008	30 %	2374	15%
2009	30 %	2803	18%
2010	30 %	3361	22%
2011	25 %	3966	26%
2012	25 %	4722	31%
2013	20 %	5477	36%
2014	15 %	6158	40%
2015	15 %	6940	45%

Table 6-2: The expected development of the total amount of biogas produced in Germany. The growth is only related to centralised and farm-scale biogas plants. No growth is expected from sewage sludge plants or landfills.

Detailed explanations of the calculations that have been made in order for other countries to close the production gap to Germany with 50 % are presented in Appendix B.

6.2 Sweden

6.2.1 Sweden – Planned Projects

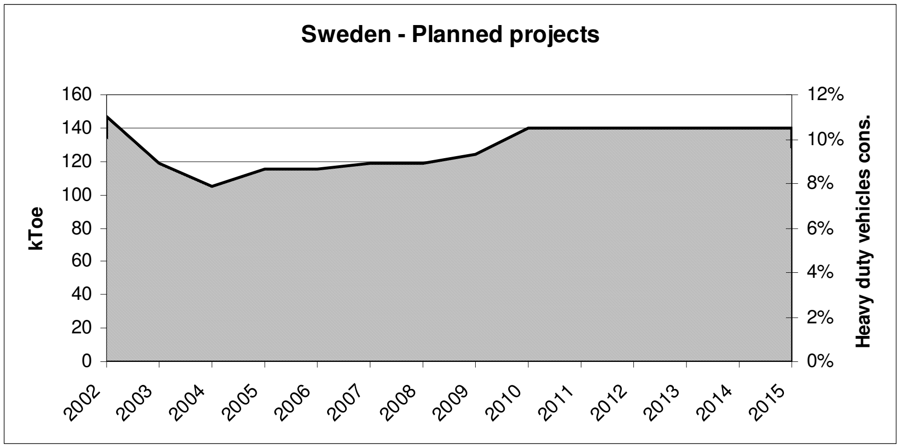

Figure 6-1: Biogas development in Sweden based on planned projects.

Sweden's total increase in its biogas production will be 21 % between the years of 2005 and 2015 when only considering projects that are under construction or in a planning phase. This increase comes from 6 different projects, of which the planned plant in Gothenburg is the largest. Its total capacity is estimated to correspond to 1.4 ktoe a year, and should be in operation 2009. However, the total financing of this project is not solved yet and the construction has therefore not been confirmed.

6.2.2 Sweden – Catching Up

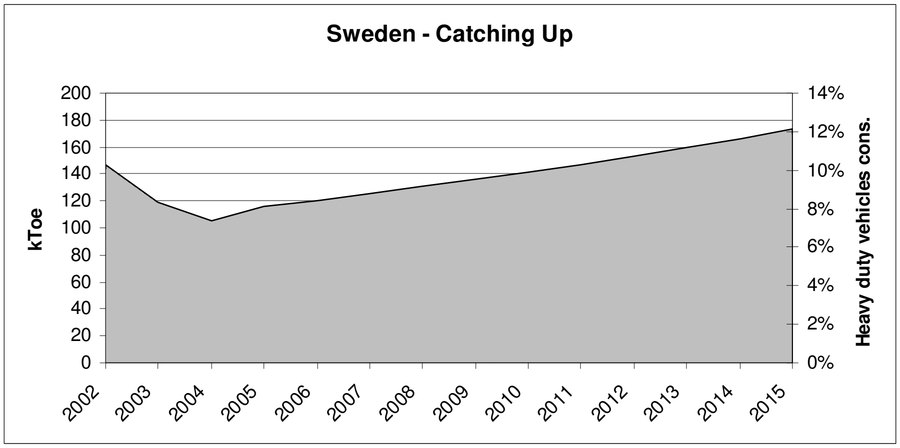

Figure 6-2: Biogas production forecast for Sweden based on a catching up approach.

Since Sweden currently is the number one country in Europe when it comes to the production of biogas from sewage sludge, the catching up calculation illustrated above only concerns landfill gas and AD plants. The catching up process would mean an increase of the biogas production with 49 % between the years of 2005 and 2015, which corresponds to a yearly increase of 4 %.

6.2.3 Sweden – Feed-In Tariff

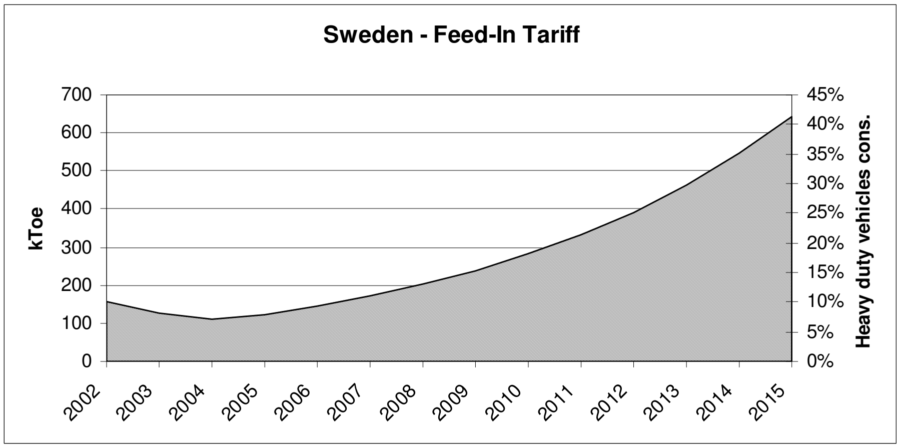

Figure 6-3: Biogas production forecast for Sweden based on feed-in tariffs.

If Sweden should implement competitive feed-in tariffs and reduce the gap to Germany when it comes to the amount of biogas produced per inhabitant, they would have to have a yearly increase in their biogas production of 18 %. This yearly increase corresponds to a total increase between the years of 2005 and 2015 of over 420 %.

6.3 Denmark

6.3.1 Denmark – Planned Projects

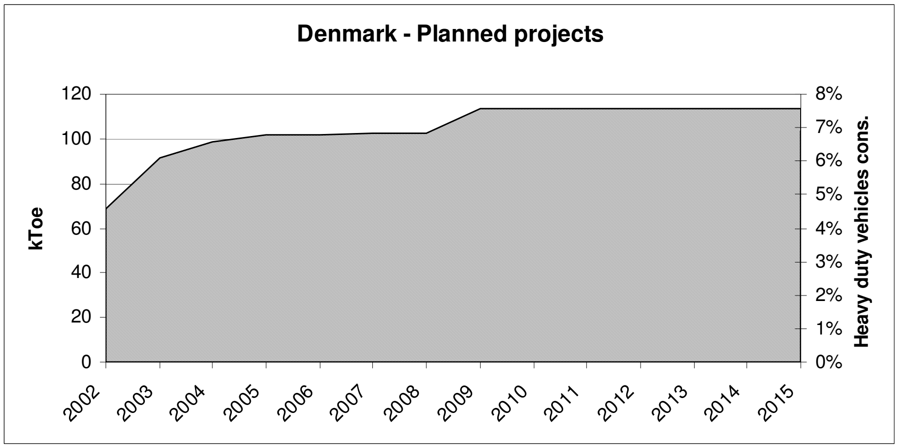

Figure 6-4 Biogas development in Denmark based on planned projects.

As illustrated by Figure 6-4, the biogas production in Denmark will remain stable until 2015, except for the increase in 2009 when the plant in Holstebro will be operational, when only projects that are known today are taken into consideration. A small AD-plant in Foulum will be operational in 2007, but this plant will only marginally contribute to Denmark's biogas production (Holm-Nielsen, 2006). The total increase illustrated in Figure 6-4 is 11 % between 2005 and 2015, which corresponds to a yearly increase of only 1 %.

6.3.2 Denmark – Catching Up

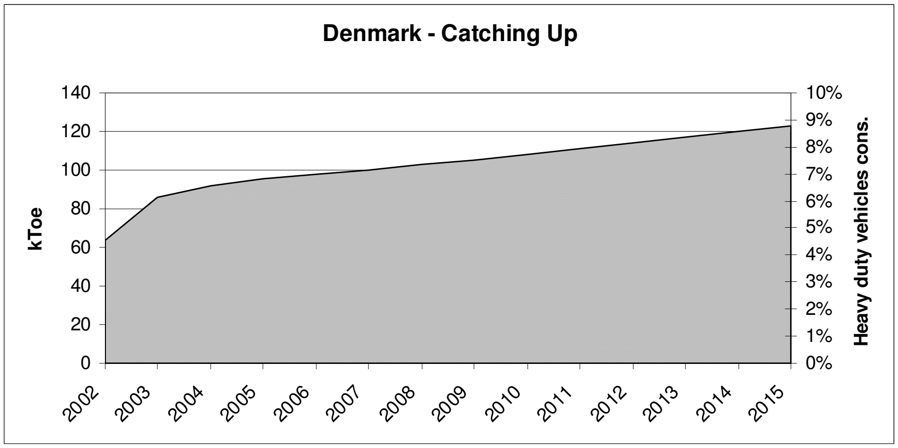

Figure 6-5: Biogas production forecast for Denmark based on a catching up approach.

Denmark is one of the frontrunners when it comes to the production and use of biogas. The catching up forecast presented in Figure 6-5 demonstrates therefore a modest total increase of 25 % between 2005 and 2015, which corresponds to a yearly increase of 2 %. Denmark is the number one country among the European countries when it comes to the production of biogas from centralised biogas plants and number three when it comes to the production of biogas from sewage sludge (EurObserver, 2006). On the other hand, they are the eleventh best perfoming country in Europe concerning of landfill gas extraction per inhabitant, far behind countries like the UK and Germany. This can be explained by that the centralised biogas plants are used instead of landfills for different types of organic waste (Raven and Geels, 2006) and Danish landfills were early on equipped with extraction systems which implies that the extraction rate has decreased. Although the Danish landfill gas extraction will not increase increase in the future, the forecasted increase of this deposit might be achieved through the other deposits.

6.3.3 Denmark – Feed-In Tariff

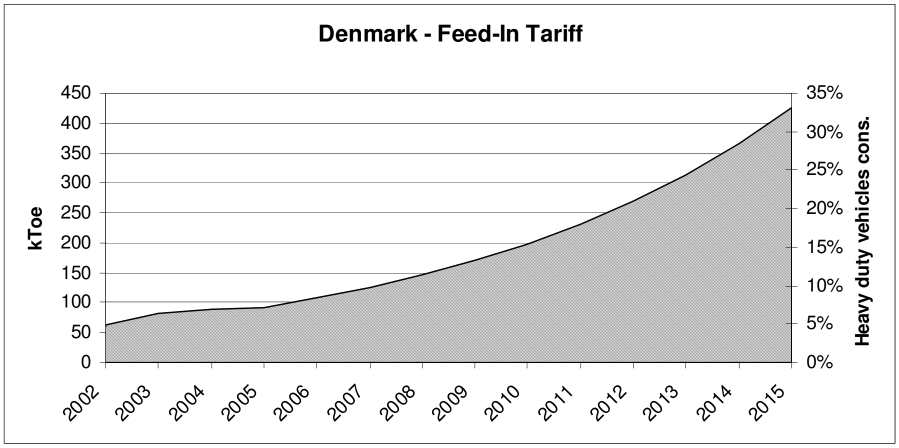

Figure 6-6: Biogas production forecast for Denmark based on feed-in tariffs.

If Denmark should implement a feed-in tariff based system for the promotion of biogas and reduce the gap to Germany when it comes to the amount of biogas produced per inhabitant, they would have a yearly increase in their biogas production of 17 %. This yearly increase corresponds to a total increase of 362 % between 2005 and 2015.

6.4 Germany

6.4.1 Germany – Planned Projects

In Germany, 50 new plants are estimated to be put into operation every month (Weiland, 2006). These plants are generally operated with energy crops, with or without the addition of manure (Weiland, 2006). The average electrical effect of the plants is 100-150 kW (Berndt, 2006). The large amount of new plants constantly being put into operation, in combination with their relatively small sizes in terms of power generation capacity, makes it difficult to get an overview of all the plants that are under construction or in the planning phase. Therefore, the type of forecast made for the other countries has not been made for Germany.

6.4.2 Germany – Catching Up

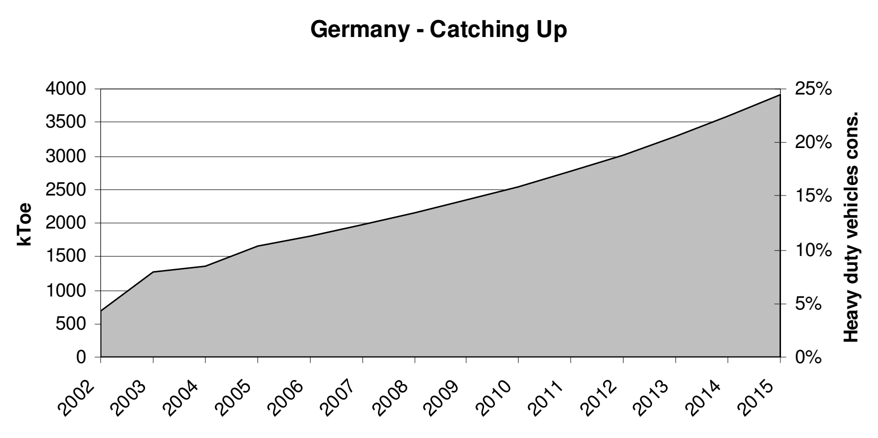

Figure 6-7: Biogas production forecast for Germany based on a catching up approach.

For Germany, a best practice approach has been used instead of a second best practice approach, as used for the other countries. This is explained by that Germany already is the second best producer of biogas when it comes to the amount of biogas produced from all the three categories, which are landfills, sewage stations and AD plants. According to the graph above, Germany would increase its biogas production with 135 % if a catching up approach is used. This corresponds to an yearly increase of 9 %. This increase is related to a total increase of 290 % in the production of landfill gas, 72 % increase in the production of sewage sludge gas and 35 % increase in the production of biogas from AD plants.

6.4.3 Germany – Feed-In Tariff

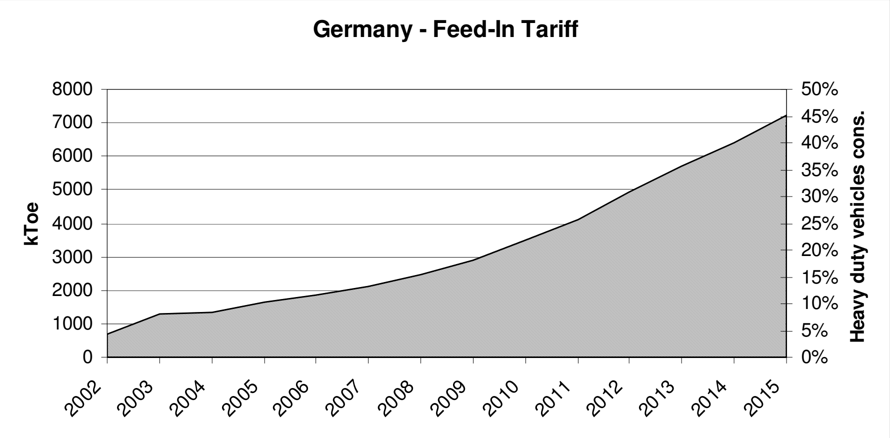

Figure 6-8: Biogas production forecast for Germany based on feed-in tariffs.

As explained in Chapter 5, Germany has been used as a baseline for the other countries feed-in tariff forecasts. The expected development for Germany is illustrated in Figure 6-8 and explained more thoroughly in Chapter 6.1.3. The total increase between 2005 and 2015 is 288 %, which corresponds to an average yearly increase of 15 %. The forecast is based on the previous development patterns seen in the construction of farm-scale and centralised biogas plants since the new feed-in tariffs were introduced.

6.5 The UK

6.5.1 UK – Planned Projects

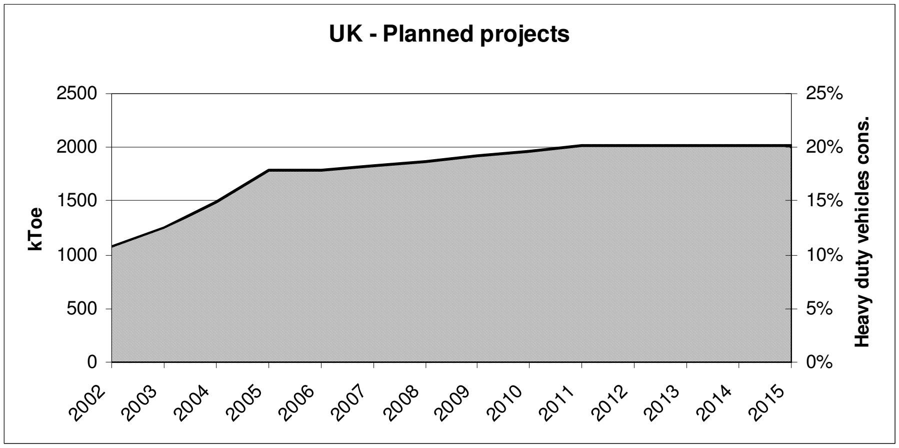

Figure 6-9: Biogas development in the UK based on planned projects.

There are currently four AD-plants in the UK that are under construction or in a planning stage. (REA, 2006a) Another 50 landfills are expected to start energy production from biogas (DTI, 2006). The date for when these plants are operational is however unclear. The added biogas production for these plants – where the date they are expected to be operational is unknown – are therefore distributed over a five year time span, from 2007 until 2011. The total increase between 2005 and 2015 is 13 %, which corresponds to an average yearly increase of 1.2 %.

6.5.2 UK – Catching Up

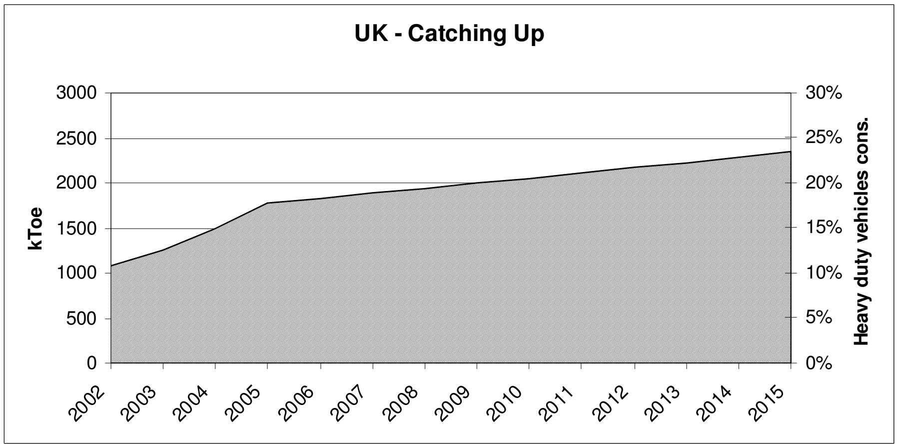

Figure 6-10: Biogas production forecast for the UK based on a catching up approach.

For the UK, a catching up approach implies a yearly increase that is lower than the increase that can be observed between the years of 2001 and 2005. The total increase from 2005 till 2015 is 32 %, which corresponds to a yearly increase of 3 %. The UK is currently Europe's largest producer of landfill gas, both in absolute figures and per inhabitant. However, they are far behind countries like Denmark and Germany when it comes to the amount of gas produced at AD-plants, and concerning the amount of gas produced from sewage sludge. The increase that is illustrated in the figure above illustrates how a catching up process in these two areas would affect the country's total biogas production. That is, an increase in the amount of gas produced from landfills is not included in the graph since the UK already is the number one country in that area.

6.5.3 UK – Feed-In Tariff

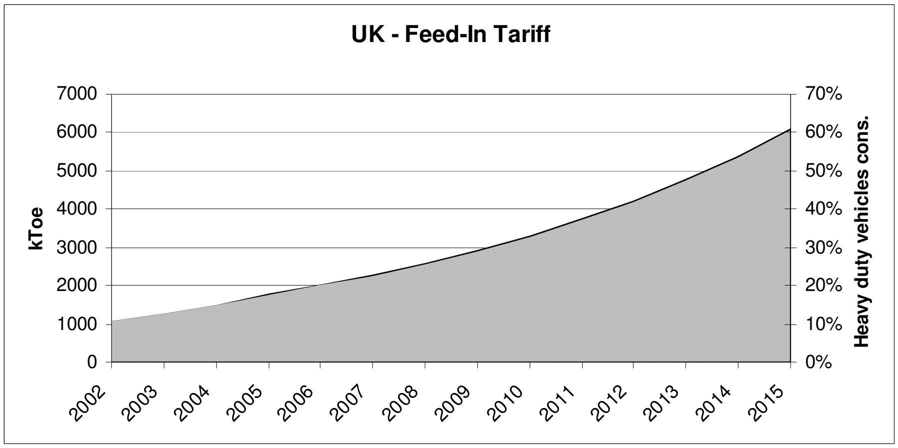

Figure 6-11: Biogas production forecast for the UK based on feed-in tariffs.

The graph above illustrates an increase of 255 % between the years of 2005 and 2015, which corresponds to a yearly increase of 14 %. Germany has had an impressive increase when it comes to AD-plants, in contrast to the UK where landfills have been the main contributor to the country's production of biogas. However, if the UK decides to shift from landfills to the use of AD-plants as an answer to the EU-directives concerning the reduction of the disposal of MSW and organic waste, the amount of biogas extracted per ton of waste would increase. Nevertheless, governmental policy changes are necessary to be able to shift the UK's waste treatment strategy for the promotion of energy production from biogas coming from AD-plants instead of from landfills.

6.6 France

6.6.1 France – Planned Projects

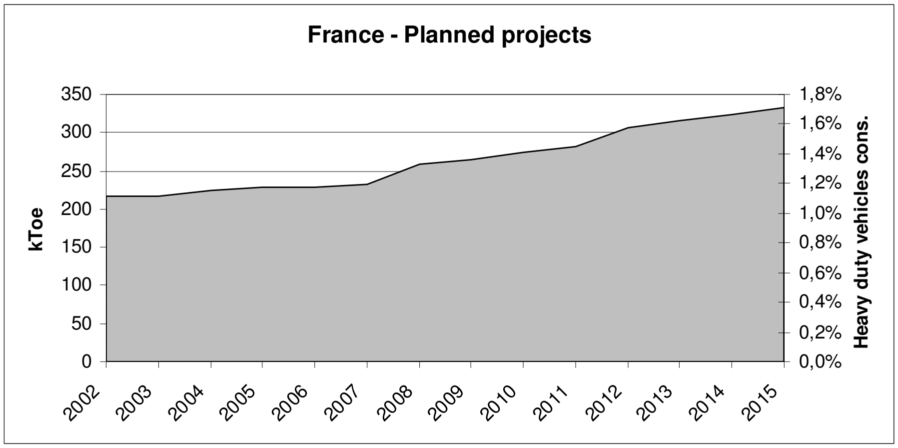

Figure 6-12: Biogas development in France based on planned projects.

There are currently 14 ongoing projects in France concerning new AD-plants (Gaz de France and ADEME, 2005; Servais, 2006). The figure above demonstrates a total increase of 46 % between 2005 and 2015, which corresponds to a yearly increase of 4 %. For some of the planned projects, it is unclear when the plants will be operational. This can be explained by that some of the projects are still open for offers from suppliers, and dates concerning the start of the construction of the plants are in these cases not always announced. For these plants, their contribution to the amount of biogas produced in France is evenly distributed over the time span 2009 until 2015. The largest plant currently planned in France is the one in Romainville, a suburb north of Paris. The plant is planned to be in operation in 2012 and will treat about 200 000 tons of waste every year, which corresponds to a yearly production of biogas of 13 ktoe (Gaz de France and ADEME, 2005).

6.6.2 France - Catching Up

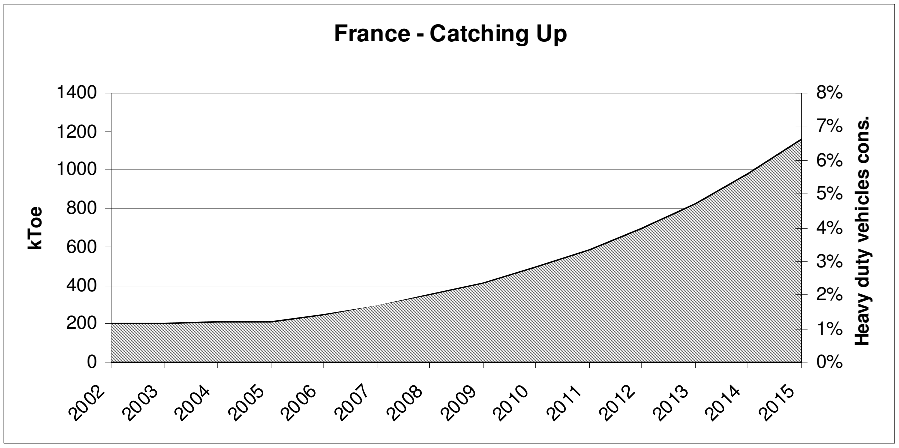

Figure 6-13: Biogas production forecast for France based on a catching up approach.

The graph above demonstrates an impressive increase in the production of biogas when a catching up approach is applied. The total increase during the time span 2005 till 2015 is 456 %, which corresponds to a yearly increase of 19 %. This demonstrates that France has a large unused capacity in terms of feedstocks suitable for the production of biogas. This is also pointed out by EuroObserver and by the French biogas report conducted by Gaz de France and ADEME in 2005 (EurObserver, 2006; Gaz de France and ADEME, 2005).

6.6.3 France - Feed-In Tariff

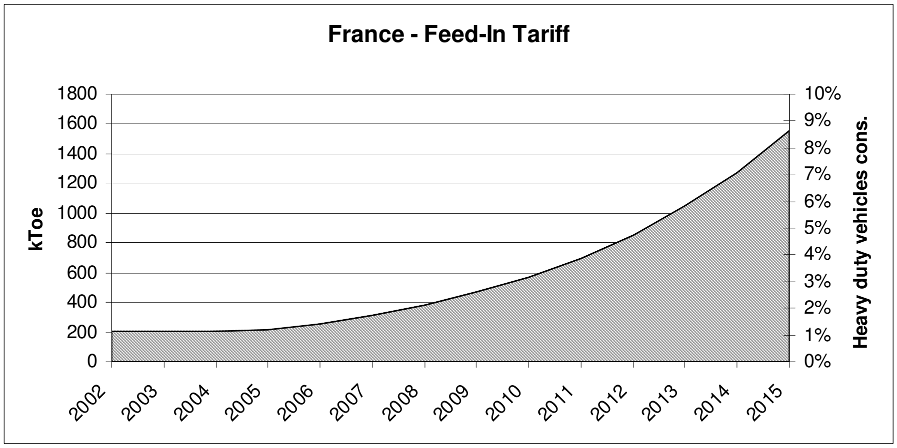

Figure 6-14: Biogas production forecast for France based on feed-in tariffs.

Figure 6-14 above demonstrates a yearly increase of 22 %. This yearly increase corresponds to a total increase between the years of 2005 and 2015 of 638 %. France has already introduced competitive feed-in tariffs, and as mentioned in Chapter 6.6.1, many biogas projects are already in the planning stage or under construction. It will be interesting to follow the development in France and see whether the development will be like in Germany.

7 European Forecasts – Conclusions

Table 7-1 below gives an overview of the forecasts presented in Chapter 6. It is clear that the feed-in tariff scenario, based on the German development, is the one with the biggest impact on the respective countries biogas production. The biogas production would in 2015 correspond to between 9 % and 60 % of the total heavy duty vehicle diesel consumption in the respective countries, based on the fuel consumption presented by the European Commission and Eurostat for the year of 2003 (European Commission and Eurostat, 2005).

Country	Type of Measure	Production 2005	Planned Projects	Catching Up	Feed-In
Sweden	Production (ktoe)	116	140	173	605
	Increase	-	21%	49%	422%
	% of heavy transp.	8%	10%	12%	41%
Denmark	Production (ktoe)	92	103	119	426
	Increase	-	12%	29%	363%
	% of heavy transp.	7%	8%	9%	31%
Germany	Production (ktoe)	1594	-	3783	6940
	Increase	-	-	137%	335%
	% of heavy transp.	10%	-	24%	45%
UK	Production (ktoe)	1783	2014	2356	6097
	Increase	-	13%	13%	242%
	% of heavy transp.	18%	20%	23%	60%
France	Production (ktoe)	209	306	1163	1543
	Increase	-	46%	456%	638%
	% of heavy transp.	1%	2%	7%	9%
Total 5	Production (ktoe)	3702	4157	7594	15611
	Increase	-	12%	12%	322%
	% of heavy transp.	8%	9%	16%	34%

Table 7-1: An overview of the impacts that the three forecasts have on the biogas production in the five countries.

All forecasts indicate that Germany and the UK will remain the dominant biogas forces in Europe the coming ten years. Although all forecasts indicate a substantial biogas growth in France, it will not have the same impact if used for the country's heavy duty vehicles. This is related to the fact that France today has a very low biogas production, per inhabitant and in total. It is also worth mentioning that France has a high consumption of diesel fuel compared to the other countries, which also gives a lower potential of the biogas produced when compared with the heavy duty vehicle consumption. On the other hand, as mentioned in Chapter 6, France has just implemented new feed-in tariffs that makes the production of electricity from biogas economic beneficial, which is expected to have an impressive impact on the construction of new plants. France is also the country that currently has the biggest increase in percent when only considering the plants that are currently being planned or under construction, which is a further indication on that the development in France is gaining momentum and starting to catch up with the other countries' biogas production.

Regarding the credibility of the scenarios presented in Chapter 6 and summed up in Table 7-1, a few comments can be made. The first scenario, based on planned projects, can be argued to represent a very modest prognosis of the biogas development. This scenario is more of an indication on what is happening in the countries during 2007 and 2008, and should not be used as a baseline for a prognosis of the actual production of biogas in 2015. It is simply impossible to predict the development on a per plant basis for the upcoming ten years. The other two scenarios – the catching up and feed-in tariff scenarios – are more relevant. First of all, the catching up forecast is interesting since the countries in Europe are starting to strive towards the same targets set by the EU when it comes to the use of renewable energy sources and the handling of waste. However, looking at the status of some countries in Europe today, one might believe that these policies are empty words, but as some countries show the way for better waste handling and use of renewable energy sources, the pressure will likely increase on those countries that can not or have not made an effort to conform to these directives. The catching up scenario can in these situations act as a demonstration on the potential of biogas as a renewable energy source and as evidence on the maturity of the technology since Germany already has proven it to be possible to achieve such a production of biogas.

The feed-in tariff scenario implies a fourfold increase in the production of biogas for the five countries in 2015 compared with in 2005. This might appear as a sensational increase, but the corresponding yearly increase is 15 %, which might appear as a less striking growth figure for an emerging technology. As earlier mentioned, this growth figure is also in line with developments in other technologies within the energy sector, especially the diffusion of wind turbines, as described in the beginning of Chapter 6. However, for some countries the feed-in scenario requires a shift in the type of policies used for the promotion of biogas. France has already implemented similar policies that are used in Germany, and the feed-in tariff scenario can therefore be regarded as particularly relevant for France. German biogas companies are already starting to establish themselves on the French market. The fact that the French biogas development can take advantage of a fully developed network of technology suppliers, experts, entrepreneurs and know-how from the German market makes the feed-in scenario a credible estimation of the biogas production in 2015.

For the remaining three countries presented in Table 7-1, it is less apparent what will happen. There is a possibility that the European Commission suggests policy measures based on feed-in tariffs for all member countries, even though this implies a shift in the Commission's strategy to only suggest targets for the use of renewable energy sources and letting the countries decide by themselves what policy measures to implement. The European Commission has recently suggested new targets for the use of renewable energy sources. The target of 20 % for 2020 would according to the Commission imply a production of 25 Mtoe of biogas, used for the production of electricity (Hodson, 2007). This corresponds to a fivefold increase of the production of biogas in the EU compared with in 2005, which is very well in line with the feed-in scenario presented in this report. The European Commission's calculations are based on a complex set of variables, where the focus has been to make an assessment of the best renewable energy sources to use, from an economical point of view, for reaching the 20 % target (Hodson, 2007). This makes the feed-in scenario into a credible assumption for the biogas development in Europe if the binding target of 20 % for 2020 is set. However, the target needs the approval of the European parliament, which should not be a problem since they have previously been in favour of more progressive renewable energy targets. However, the target also needs the approval of the Council, which may be a more uncertain procedure.

It becomes clear that the future of biogas is to a large extent a political question. So is also the case of how the produced biogas should be used. Politicians and policy makers have until now focused on the production of electricity or heat. This brings us to the question; what needs to be done in order to realize the potential of biogas as vehicle fuel? This question will be the central theme in the next chapter.

8 Analysis of the emerging bio-methane TIS

Previous chapters have covered the current European biogas production and forecasts for future biogas production have been presented. Further on, the future biogas production has been translated into a bio-methane potential as vehicle fuel for heavy duty vehicles.

This chapter will deal with the issue whether this potential can and will be realised or not, according to the secondary purpose of this thesis. Due to the complexity of the issue, the analysis will deal with identifying some of the factors that are likely to be decisive for such a development. Therefore, drivers, functions and obstacles for the European bio-methane TIS will be analysed. This analysis will also involve competitive aspects of the European bio-methane TIS compared to other TISs focused on conventional fuels, other bio-fuels and biogas for electricity production.

Since bio-methane is used as a vehicle fuel primarily in Sweden and sparsely in the rest of Europe, the analysis will focus on Sweden and on those European countries that have a large potential, like Germany and the UK. Other European countries will, however, also be briefly covered through examples.

The theoretical framework outlined in chapter three will serve as a basis for this analysis. The different actors, networks and institutions related to the European bio-methane TIS will be discussed and their importance for the development and diffusion of bio-methane will be examined. To start with, these actors, networks and institutions that constitutes the European bio-methane TIS will be identified and described.

8.1 Actors

The European bio-methane TIS consists of several groups of actors. The most important ones are the vehicle manufacturers, biogas producers and up-graders (i.e. sewage stations, landfills, AD-plants with gas upgrading), gas companies and industrial associations. However, these actors' degree of activity, and their importance for the development of the bio-methane fuel TIS, vary between different European countries. As earlier mentioned, bio-methane is sparsely used to fuel vehicles in Europe and quite naturally, more actors are present and to a larger extent active in Sweden where bio-methane have experienced the most positive diffusion.

8.1.1 Vehicle manufacturers

In order for a new fuel technology to diffuse it needs to be backed up by strong actors that have the financial power to develop and market new engine technology. Since vehicle manufacturers generally are large companies with the possibility to influence governmental policy makers, the vehicle manufacturers involved in the bio-methane TIS play a very crucial role. Volvo Cars was previously a strong and important actor for the development of the TIS in Sweden, but has in 2006 decided to stop their production of gas vehicles. They can therefore no longer be regarded as an important influencer for the promotion of biogas as a vehicle fuel. However, other automotive manufactures, like Mercedes, Citroen, Fiat, Volkswagen and Opel still offer a wider range of gaseous light duty vehicles (Miljöfordon, 2006).

Concerning heavy duty vehicles, Iveco, MAN, Mercedes and Volvo all offer trucks or busses that can run on bio-methane. However, not all manufacturers actively promote bio-methane since the vehicles run just as well on natural gas. Iveco for example, manufacture light and heavy gas trucks as well as busses and serve relatively large segments in Southern Europe. However, bio-methane is sparsely used in the South of Europe and for that reason Iveco see themselves as natural gas rather than bio-methane vehicle providers.

The Southern European natural gas vehicle market does, however, have a positive influence on the bio-methane TIS. As pointed out by Ingelman at Fordonsgas, the natural gas vehicle market provides excellent vehicle technology for the bio-methane TIS (Ingelman, 2006). Even though vehicle manufacturers play a very important role by providing the market with vehicles that are able to run on bio-methane, they can not be seen as important actors for promoting bio-methane vehicles since no attempts are made to influence policy makers and the general public opinion in favour of bio-methane. Instead, they seem to focus on the second generation of bio-fuels (Tentscher, 2007).[14]

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[14] The definition of second generation bio-fuels generally includes fuels produced from biomass through gasification.

8.1.2 Equipment Suppliers

Due to the feed-in tariffs and the resulting biogas development in Germany, a totally new industry has emerged around digestion of organic waste and agricultural energy crops. In other words, the German biogas TIS has passed its formative phase and entered a growth phase. The range of actors in this industry is broad and includes suppliers of complete digestion plant solutions, suppliers of special components and consultants for planning and project management (Fachverband Biogas, 2006).

At this point in time German equipment suppliers see the domestic market as the most important. In a near future this could change according to Owe Jönsson, since it is likely that the feed-in tariffs will become restricted in Germany, just like it Austria where a maximum number of feed-in tariffs grants for biogas production was settled during 2006 (Jönsson, 2007). Even though suppliers like Schmack Biogas and BTA still consider the German market as the most important they do also acknowledge that foreign markets like for example France is becoming more important (Wiljan, 2006; Winkler, 2006). According to Dieter Korz at Ros Roca Internacional, one of the major technology suppliers in Europe, a great market potential also lies in new EU member states in Eastern Europe, since they with time have to apply to the EU waste directive (Korz, 2006). Under the right conditions, a rapid biogas production development could therefore take place in foreign markets since no domestic equipment industry needs to be established and built from scratch. Instead, German equipment supplier could quickly enter these markets.

Even though there are several strong actors within the equipment suppliers for the production of biogas, there are no strong actors when it comes to equipment suppliers for the upgrade technology. According to Owe Jönsson, when it comes to the upgrade technology, the companies' technology solutions are peripheral rather than core activities for these actors (Jönsson, 2007).

The examples of different technology suppliers above, display some of the conflicting strategies in Europe at present. Domestic focus and lack of European wide visions can be argued to signify equipment suppliers' actions within the European biogas and bio-methane TISs. In the future, suppliers of biogas solutions can very well become more internationally active but concerning suppliers of bio-methane upgrading technology such a development is more uncertain.

8.1.3 Biogas and bio-methane producers

As mentioned earlier in this report, biogas is produced at landfills, sewage waste stations, centralized and farm scale biogas plants. While the last type of plant is operated by farmers, the former three are generally operated by municipally owned companies. Private companies are also beginning to show interest in producing biogas and bio-methane at centralized plants for power of vehicle fuel purposes.

Biogas and bio-methane producers can therefore be described as a rather diverse set of actors of different size, resources and political power. A feature that farmers and municipal companies share is that they operate on a local or regional level. At this level, municipal companies can be very influential and gain political support for producing biogas from municipal organic waste at centralized biogas plants, and thereby supplying renewable energy. There are obvious reasons for why municipalities are the most important bio-methane producers. First of all, they are generally the most important customers for the bio-methane produced. Investments in biogas production and upgrade technologies are often motivated through its benefit to the public transportation system, i.e. that the city will be able to have “green” busses running on biogas. Secondly, they are generally responsible for the handling of the municipal waste, i.e. one of the feedstocks used for the production of biogas, and see the opportunity to solve their waste handling problems while at the same time producing useful bio-methane (Hitzberger, 2006).

8.1.4 Natural Gas Companies

Since biogas historically has been produced by municipalities and used for heat and electricity production, large natural gas companies have not shown much interest for biogas and bio-methane upgrading. According to Peter Boisen, larger natural gas companies have also not been particularly interested in promoting and selling their natural gas as a vehicle fuel since distributing natural gas to gas power plants or households have been, and continue to be, larger and more important markets (Boisen, 2007).

However, large companies are not the only players in the European natural gas industry. In fact, Gunnar Ingelman described the industry as historically fragmented with large amount of small, regionally active natural gas companies (Ingelman, 2006). This view was also shared by Peter Boisen who also added that it is especially small and regional German natural gas companies who find it worthwhile to distribute gas to natural gas vehicle fuelling stations (Boisen, 2007).

The situation described above could change dramatically. Like oil, natural gas is also a finite resource and is to an increasing extent being imported to Europe. In order to secure future supplies, larger gas companies are beginning to see the possibilities with locally produced bio-methane (Jönsson, 2007). Further on, if the market for gaseous driven vehicles will grow larger, then larger natural gas companies could not afford to deny natural and bio-methane distribution to vehicles.

In Germany, gas companies' attitudes have already begun to change. Before, bio-methane was seen upon as an unclean alternative. They argued that it could contain toxic micro-organisms that could be dangerous for humans when the gas was used in households, i.e. for cooking (Jönsson, 2007). However, the attitude have now changed and biogas is accepted to be injected in the natural gas grid (Tentscher, 2007). Another sign of change is the power and gas provider E.ON's decision to enter the bio-methane industry. Although the energy group previously has supported a number of biogas plants in Germany, it is their Swedish subsidiary that has proven that bio-methane injection to the natural gas grid can be both successful and efficient (E.ON Energy, 2006). If more large energy or gas companies will follow E.ON's track, the bio-methane TIS would benefit from a powerful base of actors with financial and political power to fight for the diffusion of the bio-methane TIS. Even if they can promote bio-methane upgrading and injection into the natural gas grid, it is still highly uncertain that companies like E.ON fully support the use of bio-methane as vehicle fuel on a European level.

The first step in that direction would be to support infrastructure investments in filling stations for gas vehicles. In Sweden, the bio-methane market and its use as vehicle fuel is already supported by E.ON. Another supporting company is DONG, a Danish natural gas company with shares in Fordonsgas, a gas vehicle filling station supplier in Gothenburg. The importance of infra structure providers in discussed the following subchapter.

8.1.5 Infrastructure providers – filling stations

Filling stations have an important role to play for the development of the TIS. The use of gaseous fuels needs new infrastructure in the form of filling stations adapted for gaseous fuels instead of liquid fuels. The construction of a biogas pump costs more than ten times more than the construction of a conventional pump for liquid fuels[15] (Ingelman, 2006). This is one of the explanations for why the construction of new biogas or natural gas filling stations has been slow. The importance of filling stations for the diffusion of the TIS can be illustrated by Volvo Cars' decision to stop their production of gas vehicles, which is motivated by the lack of infrastructure, i.e. filling stations (Swärd, 2006).

Another possible explanation for the slow development of the construction of pumps for methane gas might be that the filling stations generally are in the control of some of the large oil companies. The incumbent oil companies tend to prefer other bio-fuels than biogas, much because that they do not posses the technology for the production and upgrade of biogas (Hitzberger, 2006) and because biogas is regarded as a substitute to their existing product portfolio in contrast to other liquid bio-fuels that can be blended with the existing fossil fuels (Boisen, 2006a; Hodson, 2007). This would also explain why methane gas pumps generally are build and operated by separate companies outside the traditional petrol industry.

8.1.6 Industrial associations

There are several organisations working for the promotion of biogas in the European countries. The domestic market is the most important for these organisations, particularly for those involved with upgrading of biogas into bio-methane. The only organisation that can be argued to act on an international level for the promotion of bio-methane as a vehicle fuel is the European Natural Gas Vehicle Association (Boisen, 2007; Hitzberger, 2006; Hodson, 2007; Ingelman, 2006; Tentscher, 2007), henceforth referred to as ENGVA. However, as the name indicates, the organisation was originally working for the promotion of natural gas vehicles, and can be argued to use biogas as a way of giving legitimacy to the use natural gas as a vehicle fuel. ENGVA argues that natural gas

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[15] The construction of a fuel pump for liquid fuel costs 250 000 SEK, methane pump costs 3-4 MSEK

has an important role to play in the transition from fossil fuels into bio-fuels (Boisen, 2006c). On the other hand, others argue the opposite. In a recent study conducted for the Swedish Energy Agency[16], it is claimed that an enlargement of the Swedish natural gas network would be a blocking factor for the diffusion of renewable energy sources in general, and for biogas in particular (Neij et al., 2006).

The European Biomass Association (henceforth AEBIOM) is another organisation, based in Brussels, with the aim of representing European biomass interests on an EU level. The members of the association are generally local biomass interest groups from various European countries, such as SVEBIO[17] from Sweden, DANBIO[18] from Denmark or ITABIA[19] from Italy. AEBIOM is a strong actor on a European level for the promotion of renewable energy sources, and it could be assumed that they are an important actor for the diffusion of the European biogas fuel TIS. However, this is not the case. This might be explained by that AEBIOM is supposed to represent the European biomass interests, an ambitious task which sometimes implies conflicting interests. It seems like AEBIOM do not even consider biogas as an interesting alternative to conventional vehicle fuels. This is demonstrated by their statement that renewables can be categorized into three main markets, namely heat, electricity and liquefied bio-fuels (AEBIOM, 1998, 2004). Gaseous fuels, i.e. biogas, are not even mentioned as an alternative fuel. This implies that AEBIOM, the strongest actor on a European level for the promotion of renewable energy sources, has a negative influence on the biogas fuel TIS.

In sum, there are a wide range of actors involved in the bio-methane TIS but most of these actors are not specifically focused on promoting the diffusion of bio-methane as a vehicle fuel. Although, vehicle manufacturers offer gas vehicles it is a peripheral rather than a core activity. Equipment suppliers mainly serve biogas producers that are using biogas for electricity and heat production, while bio-methane upgrading technology is supplied to a smaller market segment, concentrated to Sweden. Support for this market is given by ENGVA who are lobbying for greater usage of gaseous driven vehicles, in contrast to AEBIOM that do not make any claim for supporting the bio-methane TIS. An important contribution to the technology diffusion is made

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[16] Svenska Energimyndigheten
[17] Swedish Bioenergy Association
[18] Danish Biomass Association
[19] Italian Biomass Association

by infrastructural providers that invest in bio-methane filling stations. Some of the infrastructure providers are subsidiaries to gas companies, which is a category that might become more involved, and promote bio-methane TIS to a greater extent in the future.

8.2 Bio-methane Networks

Networks are always important for the diffusion of a new technology. However, for a new and technically interrelated technology that is dependent on new infrastructure, networks are of fundamental importance (Bergek et al., 2006b). This is therefore also the case of the bio-methane TIS, where infrastructure in the form of adapted filling stations are a prerequisite for the technology to diffuse. Additionally, networks are important for giving a voice to the TIS in a socio-political institutional arena, (Bergek et al., 2006b) which also is an important issue for the European bio-methane TIS.

The reason why networks are so important is because it is through networks that knowledge is shared and transferred. It is also through networks that interest can be aligned and the perception of a desirable future is shared (Jacobsson and Johnson, 2000). Accordingly, a network can become political with the objective of shaping the institutional set-up in to suit the shared interest of the network (Jacobsson and Bergek, 2004a).

Concerning bio-methane in Europe, a number of networks of the former type, dealing with information sharing, are active at a local, national and European level. Regarding the latter type of networks, with political aspirations for promoting bio-methane as a vehicle fuel, they are lacking at European and National levels.

8.2.1 Knowledge sharing networks

On an international level, the IEA is organising different working groups within different fields related to renewable energy. Task 37 is such an example, consisting of researchers and professionals from eight European countries working for the promotion of biogas as an energy source (IEA, 2006). However, this network is not focusing on bio-methane upgrading or its vehicle fuel potential. Instead, the network is a forum for researchers and professionals to share objective experiences from the various biogas projects in the different countries. This network does not have a unified agenda and does not make any attempts of influencing policy makers at a European level, even though single members of the network try to do so, on a national level (Jönsson, 2007; Willumsen, 2006).

Another European initiative is the BiogasMax project, which's aim is to demonstrate the potential of bio-methane as a transportation fuel. About 30 different actors from eight different countries take part in the project, and exchange experiences from the various ongoing projects they are involved in. The project is financed by the EU and has supported investments in biogas production plants, bio-methane upgrading and usage as vehicle fuel for public transportation in Lille, Gothenburg, Stockholm, Haarlem and Rome. According to Pierre Hitzberger, project manager for BiogasMax, the network's main aim is to share experiences and learn from one another and not to become a political network (Hitzberger, 2006).

In addition there are networks consisting of actors from a specific country or region. This is particularly the case for Sweden. The Swedish bio-methane network can however be divided into various sub-networks that have quite different characteristics. As an example, the network between filling stations, biogas producers/up-graders and consumers is well established in cities like Gothenburg, Västerås and Linköping. In Stockholm, on the other hand, there is a weak link between the different actors which results in a malfunctioning bio-methane TIS (Ingelman, 2006). The low availability of bio-methane and natural gas in the Stockholm region is a concrete example of that. The lack of communication between actors among the filling stations and the public transportation companies regarding their enlargement of their gas vehicle fleet has in Stockholm resulted in that the demand of methane gas exceeds the availability, something that could have been avoided if the filling stations were informed in advance and thereby got the possibility to adapt the infrastructure to future increases in the demand of methane gas. (Ingelman, 2006)

8.2.2 Political networks

Locally active bio-methane networks in Swedish cities like Gothenburg and Linköping have been able to politically influence their interests. At this level it is also easier to influence since, as mentioned earlier, bio-methane producers often are operated by municipal institutions that also are responsible for public transportations. As a result, the benefits of bio-methane as vehicle fuel are more apparent and the bio-methane network is more homogeneous which thereby can influence local institutions.

On a national level, one powerful political network might be entering the bio-methane TIS within a short period of time. The German Biogas Association is made up by a divers set of members within the German biogas industry, ranging from farmers, contractors, project managers and equipment suppliers. The network has had a major influence of the German biogas development by lobbying and receiving support from the German government for the implementation of the EEG law and corresponding feed-in tariffs for electricity production (Negro, 2007). According to Wolfgang Tentscher, who is lobbying for bio-methane upgrading and natural gas injection, the confidence of fellow members for upgrading has been won, but is yet to be accepted by a vote within the German Biogas Association (Tentscher, 2007). If majority will be won, the bio-methane TIS will be joined by a powerful network that can influence politics to improve conditions for bio-methane upgrading. Considering the infrastructural investments in natural gas vehicle filling stations that are being made in Germany, where 275 new natural gas filling station is planned to be constructed in addition to the current 725, bio-methane will most certainly be used as a vehicle fuel. (Das Erdgasfahrzeug, 2007; Tentscher, 2007)

To summarize, networks within the bio-methane TIS are primarily of knowledge sharing character. Exchange of experiences and learning from one another is the main focus of international networks like IEA Task 37 and BiogasMax. Despite their presence networks in Europe can be described as weak and are lacking political power to influence institutions. On a regional level in Sweden, networks between technology suppliers, producers and consumers have managed to align institutions to their interests. This has not been accomplished on an international level since no strong "political" networks exist. Potentially, this situation could change if the German Biogas Association decides to support bio-methane upgrading because it is a strong network with muscle to influence politics.

8.3 Institutions

The bio-methane TIS can be regarded as still being in a formative phase. This might explain why few institutional changes can be observed on a European level in favour for the bio-methane TIS. On the other hand, local authorities and governments are in some cases starting to implement policy measures in favour of bio-methane, which in turn also influences the outlook for a positive development of the bio-methane TIS. Institutions also refer to the cognitive rules, law and regulations that influence the TIS. Here, institutions have been categorized according to their level of influence. Municipal, government and European Union based policy makers, regulators and legislatures will be analysed below.

8.3.1 European Union based institutions

The EU is actively working in favour of renewable energy sources to reduce the Unions dependency on fossil fuels. This can be regarded as a first step in the formation of new norms and regulations in favour of the bio-methane TIS. As already mentioned, the EU bio-fuel directive clearly state that the percentage of bio-fuels for all road transports should reach 5.75 % by 2010 (European Commission, 2003b)[20]. Considering today's bio-fuel share of about 1%, the new directive supports the diffusion of bio-methane.

However, the European Commission give each member country the freedom to reach this target in their own way, since the European Commission does not give any suggestions on policy instruments or directives that ought to be used by governments for meeting such targets.
According to Paul Hodson, policy manager for renewable vehicle fuels at the European Commissions, this strategy is unlike to change, since they trust each member state to solve the issue in the best way. Further on, he argues that it is highly unlikely that any specific policies or measures will be taken concerning bio-methane as a vehicle fuel in the near future since it is not seen as potential mass market fuel (Hodson, 2007).

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[20] 5.75 % of fuels for transport should be bio-fuels by the year of 2010. However, it is unlikely that any EU countries, except for Sweden, Germany and maybe France, will reach this target.

8.3.2 Governments

The European bio-methane TIS have also encountered institutional resistance on a national level. As an illustration of the lack of governmental alignment to the national bio-methane TIS, it can be pointed out that few European countries have developed a standard for bio-methane as a vehicle fuel or adapted their laws and regulations concerning transport fuels to also include bio-methane (Jönsson, 2007). A fuel standard has only been developed in Sweden and the lack of fuel standards is something that has a negative effect on the bio-methane TIS and bio-methane diffusion (Hitzberger, 2006; Jönsson, 2007).

Governmental policies have been successful for the production of biogas and have been one of the main contributors to the positive biogas development in Germany and the UK. According to Paul Hodson, the increasing amount of extracted biogas from landfills in the UK should not be regarded as a result of successful policies. Rather on the contrary, Hodson states: *"…the waste should not have been at the landfill in the first place"* (Hodson, 2007). Either way, despite increasing biogas production, the policy focus in these countries has not involved gas upgrading and using bio-methane as vehicle fuel. Instead, the use of the biogas for the production of heat and electricity has been promoted in these countries. Even though tax exemptions for bio-fuels exist in many countries, it is still in most cases more financially interesting to use the biogas for the production of electricity and heat rather than upgrading it to vehicle fuel (Willumsen, 2006). (See Appendix F for an overview of the existing biogas policies in the European countries.)

Domestic incentives for biogas production can have both positive and negative impacts on the European bio-methane TIS. It can be argued that incentives like the feed-in tariffs in Germany, Austria and recently introduced in France, that guarantees a certain electricity purchase price also have a positive influence on the bio-methane TIS. More biogas is produced which thereby potentially could be converted to bio-methane and used as vehicle fuel. On the other hand, these incentives can also block the development of the bio-methane TIS, since electricity production is more profitable.

It is interesting to compare the development in countries where biogas feed-in tariffs for electricity production have been implemented with the development in Sweden where such incentives never have been introduced. In Sweden, the government has instead used a green certificate system, which has not generated the same economical incentives for the production of electricity like in Germany. Ironically, the failure of the green certificates to provide lucrative conditions for electricity production have implied more favourable conditions for bio-methane upgrading in Sweden. A related issue is the fact that the Swedish electricity prices have traditionally been lower than in other European countries (Jönsson and Persson, 2003). On top of that, the price for natural gas has traditionally been higher and the natural gas grid not as well built out in Sweden compared to its European neighbours. Due to a high natural gas price, bio-methane have not been out competed but rather seen as a good complement to natural gas (Jönsson, 2007). (See Appendix K for a complete comparison of natural gas prices in Europe.)

A very important government decision concerns the taxation of vehicle fuels. If a fuel is highly taxed or tax exempt makes a huge difference on the market interest for a specific type of fuel. In a emerging technology phase, the tax structure can accidentally have a very negative influence on a particular fuel, like for example for bio-methane in Finland that earlier was taxed higher than traditional fuels (Jönsson, 2007). In Sweden however, bio-methane has been attached to more favourable taxation which has been one underlying factor for its diffusion.

Consequently, a number of governmental decisions, as well as coincidences, have lead to a more developed bio-methane TIS in Sweden compared with other European countries. In contrast to Germany, the Swedish biogas production has not increased dramatically although a greater amount of the produced biogas have been upgraded and used as transportation fuel.

8.3.3 Municipalities

Local authorities are also important for the forming of new rules and norms in favour for the development of the bio-methane TIS. Again, in Sweden, municipalities have in several cities introduced various incentives, such as free parking for environmentally friendly vehicles, and in some cases even set up directives for municipal companies to use a certain number of bio-fuel cars within their fleets (Ingelman, 2006). Municipalities around Europe are also acting as pioneers in the use of bio-methane vehicles by being the important first customers that explore the new fuel technology. Municipal transportations and municipal refuse trucks serve as nursing markets for bio-methane and natural gas vehicles throughout Europe, which contributes to the development of new norms, cognitive rules and laws adapted to the bio-methane TIS.

In sum, institutions on a European, national and municipal level indirectly support the diffusion of bio-methane. Directives from the EU, intended to increase the share of bio-fuels includes bio-methane as an alternative but no specific measures or policies for supporting the diffusion of bio-fuels have been implemented. The responsibility, for reaching targets outlined in directives, is given to European governments. With the exception of Sweden, a fuel standard for bio-methane has not been implemented in the rest of Europe which is an indication that see bio-methane is not as viable vehicle fuel alternative. Instead, more support and attention is given to electricity production from biogas. In contrast, institutional support for bio-methane is often present on a municipal level since municipal transportations and municipal refuse trucks are nursing markets for bio-methane and natural gas vehicles.

8.4 Important functions within the bio-methane TIS

As described in the theoretical framework, seven key functions have been identified and mapped within emerging TISs by researchers like Jacobsson, Bergek and Negro. In this chapter, such a mapping of four of the most crucial functions within the European bio-methane TIS will be performed. These TIS functions, *knowledge creation, influence of the direction of search*, *market formation* and technology *legitimation* will be analysed with respect to driving forces and blocking mechanisms for bio-methane. Mapping of the key functions for a TIS is argued to be relevant for emerging fuel technologies such as bio-fuels, which includes bio-methane (Bergek et al., 2006a). However, the different functions should not be regarded as independent from each other (Jacobsson and Bergek, 2004b), rather highly interdependent and overlapping. Figure 8-1 illustrates the driving forces, functions and blocking mechanisms of the European bio-methane TIS, which is to be analysed.

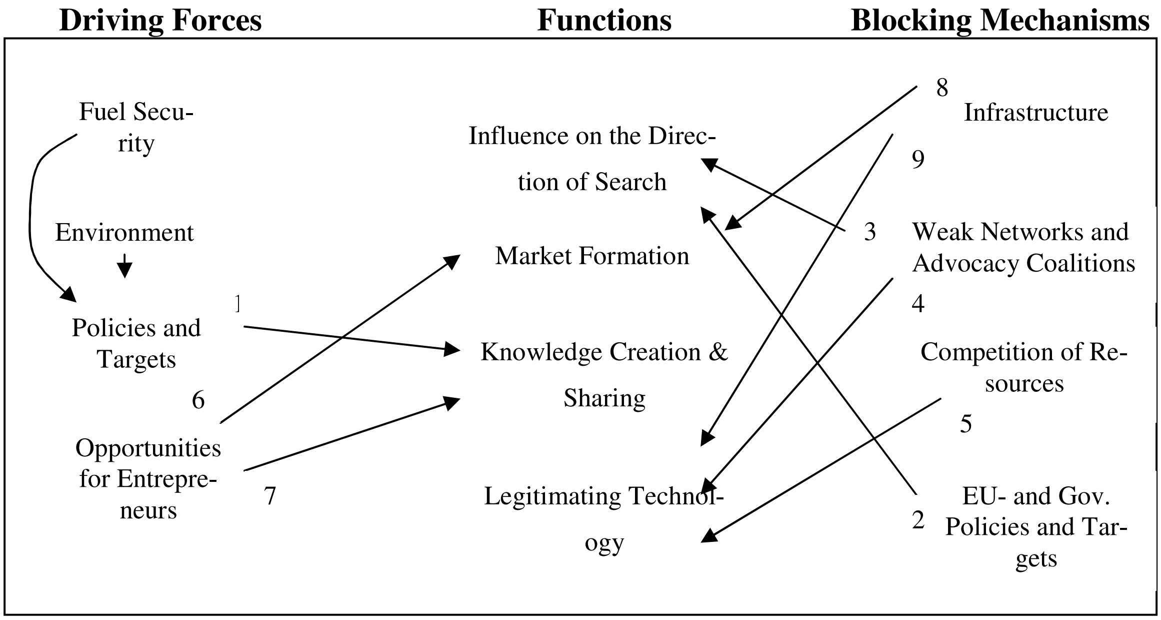

Figure 8-1: Driving forces, functions and blocking mechanisms for the European bio-methane TIS. Arrows are numbered in order to simplify the discussion below.

As mentioned already in the introduction of this thesis, the growing uncertainty regarding fuel security and the severe environmental consequences of using conventional vehicle fuels has lead to a search for alternatives. Due to the seriousness of these issues, the EU and national governments have begun to support the search for alternatives by establishing targets and policies for reducing the dependence of conventional fuels by financing local projects and supporting "green" investments. By doing so the have promoted *knowledge creating and sharing* [1] The support from the EU and governments have not been bio-methane dedicated, rather renewable energy and fuel oriented and thereby supporting a wide set of technologies and fuels that can be used for electricity, heat production as well as for fuelling vehicles. So even if EU and government policies have articulated general bio-fuel targets, estimates of future growth potentials and support for research they have not greatly *influenced the direction of search* and narrowed down uncertainty by particularly focusing on bio-methane as a vehicle fuel. On the contrary, EU- and governmental policies have blocked this possibility [2], since using biogas for electricity production has received more attention and support on a European level. Thereby the bio-methane TIS can still be described as highly uncertain in terms of regulations, which is common in a formative phase (Jacobsson and Bergek, 2004b).

The lack of institutional support is also a result of the weak bio-methane networks and advocacy coalitions with the European bio-methane TIS which also block the *influence of the direction of search* [3]. The European bio-methane TIS consists of actors not strongly tied together by networks. This is demonstrated by the fact that there is no political network or lobby organization created specifically with the purpose of representing the bio-methane TIS on a European level. The ability to influence European policy makers is vital for gaining technology *legitimacy* and for *influencing the direction of search* but is in this case lacking, and thereby these functions are blocked [3], [4]. The only lobby organization that is actively promoting bio-methane as a vehicle fuel is ENGVA, but just their name reveals that their primary focus is not bio-methane, which thereby possibly even can have a negative impact on the *technology legitimization*. The lack of European wide advocacy coalitions (Jacobsson and Bergek, 2004b) and lobby organizations was also confirmed by Paul Hodson at the European Commission, who stated that: "*In order to lobby in Brussels, you need to be an industry and bio-methane is not there yet*".

The "Political networks" are also too weak on a national level in the countries of Europe. This is demonstrated by the fact that most European countries do not even include bio-methane in their policies and regulations concerning bio-fuels and have not implemented a vehicle fuel standard for bio-methane. In the competition with other bio-fuel alternatives, the bio-methane TIS have not been able to attract powerful actors, which tend to back up other fuel technologies with stronger lobbying efforts. These mechanisms have thereby blocked the *influence on the direction of search* and *technology legitimization* functions [3] [5].

In contrast to political networks, learning and knowledge sharing networks do exist on a European and domestic level [1]. They are important for *knowledge creation* and development through contacts such as personal relationships, workshops or conferences (Bergek et al., 2006a; Negro et al., 2005; Raven and Geels, 2006). The BiogasMax project is the platform which is most focused on *creating and exchanging knowledge* within the bio-methane vehicle fuel TIS. Its importance for the bio-methane TIS is hard to evaluate since the project just has started and will continue for another two years. At this time the project does not include any financial benefits, rather the motives are display the potential of bio-methane as a vehicle fuel (Hitzberger, 2006).

Interestingly, Paul Hodson regard BiogasMax as good testing ground for local vehicle fleets which should be supported, also in the future (Hodson, 2007). National learning networks have also been created as a result of governments' attempts to decrease the dependency on oil, by supporting investments in test facilities and research regarding alternatives. Although this driving force has been general for all renewable energy sources rather than bio-methane specific, it has encouraged some entrepreneurs to enter the bio-methane sector. In Sweden this has led to a beginning of a *market formation* [6], but on a European level, entrepreneurs have mainly contributed to the *creation of knowledge* through formation of networks [7]. No European market has thereby been formed, and as argued by Simona Negro who has conducted research on the German biogas diffusion, knowledge must not only be created and shared; it must also be used in order for a TIS to gain momentum (Negro, 2007).

The technology prerequisites for a *market formation* do however exist since technology for the biogas production and bio-methane upgrading is available on the market. However, the upgrade technology is still considered as expensive which is a barrier for a rapid bio-methane diffusion (Jönsson, 2007; Lantz et al., 2007; Willumsen, 2006). There is therefore a need for new solutions or a development of current upgrading techniques if not the bio-methane *market formation* is to be blocked by competing and cheaper fuel technologies in the future. This could be accomplished by entrepreneurs and their *knowledge creation* through entrepreneurial experimentation which could become decisive for overcoming the obstacle of resource competition with other fuel technologies and thereby for the development of the bio-methane TIS. For such a development, entrepreneurs that see the potential in the fuel technology and are able to turn the potential into concrete actions and generate new business opportunities, are needed (Negro et al., 2007). Additionally, strong support from governments and the EU are needed for funding investments and R&D expenses that often are huge in the area of fuel technologies. Current policies do however block this possibility, making it difficult for small actors to be able to do any path braking advances in technology. On the other hand, the entrepreneur can also be an incumbent company that are willing to diversify its business (Negro et al., 2007) but vehicle manufacturers have so far not engaged themselves fully in the bio-methane TIS (Tentscher, 2007).

According to Paul Hodson, the barriers are too large for bio-methane to become a mass market vehicle fuel. He particularly emphasized the lacking infrastructure as the largest blocking factor (Hodson, 2007). In addition to blocking *market formation* [8], the lacking infrastructure hinders the *legitimization process* of bio-methane as viable vehicle fuel and instead attention and focus is drawn to liquid bio-fuel alternatives. These fuel alternatives compete for the same recourses, such as areas for energy crop farming, government subsidies for R&D and infrastructure investments which thereby block the bio-methane *legitimization* even further [9].

To summarize, due to blocking mechanisms, many functions that are important for the development of the bio-methane TIS are hindered. Weak advocacy coalitions have a negative influence on the *direction of search* and the technology *legitimization*. Further on, it reduces the likelihood of achieving institutional alignment which could bring about *technology legitimacy* and improve the conditions for *market formation.* Bio-methane's incompatibility with existing infrastructure is another blocking factor for these functions. Concerning infrastructure, other bio-fuels has a competitive advantage since the need for large investments is not as crucial. This is also one reason why policy makers have not implemented bio-methane specific incentives and policies, which in turn implies difficulties for those entrepreneurs that enter the bio-methane sector. The *knowledge that is created* by entrepreneurial activities *and shared* through networks is thereby not enough to drive the development of the bio-methane TIS.

9 Conclusions

The primary aim of this thesis has been to determine the current European production of biogas and how this production may develop until 2015. This issue has been approached by studying available biogas production statistics and performing interviews with some key persons in Europe. Statistics for year 2005, collected by EurObserver indicate that the European production almost reached 5 Mtoe and that the UK and Germany represented 70 % of the total volume. By now, the production is most certainly higher due to number factors. First, EurObserver has made some statistical mistakes regarding Sweden, for example, and their statistics are seen as quite low by Owe Jönsson who is contact person for the network IEA Task 37, that keep track of the biogas development in some European countries (Jönsson, 2007). Second, the strong development in Germany has continued and there are currently no signs that it will begin to slow down (Tentscher, 2007).

In order to get an estimate of the biogas production by 2015, two different types of forecasts were constructed and presented in this thesis. The first is based on the assumption that all European countries could reach the level of the second best performing country for each biogas production segment, on a per capita basis. Since Germany, according to EurObserver, had the second largest biogas production per capita for landfills, sewage stations and biogas plants (centralized and farm-scale) this forecast implies a European catch up by 2015, to Germany's level in 2005. This forecast implies that the European production would end up at 12 Mtoe by 2015 which would correspond to about 14 % of the energy consumption of Europe's heavy duty vehicles.

The second forecast is instead based upon the assumption that all European countries implement a similar policy system as Germany and experience a comparable biogas production growth. The current feed-in tariff system for electricity production in Germany has had a major impact on the biogas development and France has recently followed their path. The European Commission does also acknowledge the benefits of feed-in tariffs for the promotion of renewable energy technologies and regard it as effective policy instrument (Hodson, 2007). If introduced on a European level, the European biogas production could accelerate and reach 23.1 Mtoe in 2015, according to the feed-in tariff forecast. In terms of energy content, it would correspond to about 27 % of the heavy duty vehicles fuel consumption in Europe.

The secondary aim of this thesis has been to analyse the possibilities for realizing the potential of biogas as vehicle fuel. Instead of using the forecasted 23 Mtoe biogas for electricity production, which is the most common mode of valorisation in Europe today, it could instead potentially be upgraded to bio-methane and used as a vehicle fuel.

By analyzing the European bio-methane TIS, some of the driving and blocking factors for realizing this potential has been revealed. To start with the driving factors, in response to environmental, security and scarcity issues attached to conventional vehicle fuels, policy makers and regulators at an EU, national and municipal level have begun to look at alternatives. Policy makers at the EU have declared that the dependency on oil based fuels should decrease and have set a bio-fuel a target at 5.75 % share by 2010. This target has in some European countries been complemented by national targets, investments and regulations.

Specific policies and regulations concerning bio-methane are however lacking on a European and national level. In combination with weak "political" networks it has blocked the direction of search to be influenced. As a result, upgrading biogas to bio-methane and using it as a vehicle fuel is not the prioritized usage of biogas in Europe. This is also an explanation to why bio-methane entrepreneurs have remained on a local level, under the protection of municipal policies and incentives that have been more specific, especially in Sweden. What should not be forgotten is that bio-methane is used as fuel and the TIS is functioning on a local level in Sweden. There, instead of an obstacle, the municipal organisations have promoted the use of bio-methane as vehicle fuel since it is in line with many of their interests; biological waste treatment and recycling, possibilities for offering clean public transportations and thereby creating good publicity. On this level, policies and targets have influenced the direction of search. Increasing biogas and bio-methane production due to more reliable technology have helped to build local networks with visions and beliefs regarding the growth potential (Bergek et al., 2006a). The proximity of municipal institutions and municipal bio-methane producers has lead to a *market formation* which also has become a niche market for bio-methane vehicles, often including refuse collection trucks and public transportation busses. Nevertheless, the bio-methane TIS have not evolved from this local level and crossed national boarders within Europe.

Without dedicated policies, infrastructural investments, which are fundamental for the bio-methane TIS development, have been lagging or never been made. Especially, the lack of infrastructure has been used as an argument by potential actors against entering the bio-methane TIS and also by policy makers against the promotion of the technology. This creates a catch 22, where infrastructure investments are not made because there are no strong actors to make the investment and no or strong networks that can do political lobbying for such investments.

In order for the bio-methane TIS to develop and evolve, several blocking factors need to be addressed and solved. One of the most critical blocking factors is weak formations of networks and advocacy coalitions which hinders the technology to become a legitimate fuel option. No “political” networks have grown strong enough to influence institution and align them to bio-methane interests, which in turn have discouraged its legitimacy and thereby complicated a market formation. In order for the bio-methane TIS to grow stronger and larger on national and European level, “political” networks, which can influence institutions in favour of bio-methane on national level, must evolve. The emergence of such national networks in Germany and in the UK must therefore be seen as the first step towards realizing the European bio-methane potential as a vehicle fuel.

Since it generally takes an industry to create a lobby organization, the best support that could be given to the bio-methane TIS would be if an existing strong actor or network would join the TIS and promote the technology. At this moment, the German Biogas Association is the strongest network that potentially could come to embrace the bio-methane TIS and help it win acceptance in Germany. According to Wolfgang Tentscher, a majority of the members are in favour of bio-methane upgrading and injection to the natural gas grid (Tentscher, 2007). However, any decision to actively support bio-methane injection to the gas grid has not yet been taken. If it should happen, the European bio-methane TIS will potentially receive the support needed to win acceptance in Europe. First of all though, the German Biogas Association needs to convince the German government to alter policies and incentives and align them with the European bio-methane TIS’ needs. Previously, they have proven their ability to influence policy makers in Germany and they may have the power to do it again.

If the German Biogas Association begins working in favour of biogas injection into the natural gas grid in Germany, it would have an impact. Germany already has 725 fuelling stations for natural gas and is planning to build another 275. This implies that if bio-methane is injected into the gas grid, bio-methane will be available as a vehicle fuel on Europe's largest and most important vehicle market. Accompanied with strong actors such as gas companies who can provide further infrastructure investments, and support the production of bio-methane, the bio-methane TIS could experience rapid change. Such a development could lead the way for institutional changes, new policy incentives and gained legitimacy for the bio-methane TIS on a European level. As a result most of today's blocking factors will be addressed and solved. If such a development will take place in the coming years, the European bio-methane potential would be in the reach of realization.

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Appendix A – Alternative fuels

	Biodiesel (tons)	Biodiesel (ktoe)	Ethanol (tons)	Ethanol (ktoe)
UK	51 000	45,9		
Germany	1 669 000	1502,1	120 000	76,8
France	492 000	442,8	99 780	63,9
Spain	73 000	65,7	240 000	153,6
Italien	396 000	356,4		0,0
Netherlands		0	5 971	3,8
Sweden	1 000	0,9	130 160	83,3
Portugal	1 000	0,9		0,0
Denmark	71 000	63,9		0,0
Austria	85 000	76,5		0,0
Belgium	1 000	0,9		0,0
Greece	3 000	2,7		0,0
Ireland		0		0,0
Finland		0	36 800	23,6
Luxenburg		0		0,0
Polen	100 000	90	68 000	43,5
Slovenia	8 000	7,2		0,0
Slovakia	78 000	70,2		0,0
Hungary		0	11 840	7,6
Tjeck Rep.	133 000	119,7	1 120	0,7
Total		2845,8		456,7

l ton biodiesel =	0,9	toe
1 ton ethanol =	0,64	toe
ktoe =	1000	toe

Source: EurObserver, (2006)

Appendix B – Calculations for feed-in tariff forecast

Feed-In Tariff:

Equation 1 & 2:

$$\frac{\left(\frac{A}{I}-\frac{k}{h}\right)}{\frac{k}{h}}=2\frac{\left(\frac{B}{I}-\frac{a}{h}\right)}{\frac{a}{h}}$$

$\Rightarrow$

$$a=\frac{(2\cdot \mathrm{B}\cdot h/\mathrm{I})}{\left(\frac{h\cdot A}{k\cdot \mathrm{I}}+1\right)}$$

a = Country a’s (Any country) biogas production 2015
A = Germany’s biogas production 2005
B = Germany’s biogas production 2015
I = number of inhabitants in Germany
h = Number of inhabitants in country a
k = Country a’s biogas production 2005

All capital letters are constants, i.e. the same for all calculations. Equation 2 is used for the estimation of a country’s biogas production in 2015 based on the development in Germany. The development in Germany is based on the previous positive trend that can be observed in Germany the last couple of years and on the interviews conducted for this thesis as explained in chapter 6. The growth of the biogas industry in Germany has not been assumed to be the same every year until 2015. A weakening in the positive trend in the construction of biogas plants has been assumed. This is in line with observations from development paths that other renewable energy technologies, i.e. solar cells and wind power, have taken. Since these technologies are considered as more mature than AD-technologies,[21] they can give guidance for forecasts concerning the biogas industry. The forecast of the German biogas development is described by the table below.

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[21] These technologies are considered as more mature in Germany. For other countries, this may not be the case.

Year	Growth
2006	30 %
2007	30 %
2008	30 %
2009	30 %
2010	30 %
2011	25 %
2012	25 %
2013	20 %
2014	15 %
2015	15 %

Table A - 1: Expected growth in Germany.

Appendix C – Contacts, Conferences and Fairs

Personal communications:

Date	Name	Title/Position	Organisation	Purpose
30/8 -06	Cecilia Holmblad	Engineer	Nordvästra Skånes Renhållnings AB (NSR), Helsingborg's biogas plant	General information about the production of biogas
30/8 -06	Karin Eken-Södergård	Product manager, biogas	Nordvästra Skånes Renhållnings AB (NSR), Helsingborg's biogas plant	General information regarding biogas and landfilll gas. Provided us with documents regarding biogas
31/8 -06	Siv Flod	-	Kalmar biogasanläggning	General information about biogas
1/9 -06	Anders Assarsson	Engineering manager	Borås Renhållningsverk	General information about upgrading technologies for biogas and volumes of production.
1/9 -06	Hanna Hellström	Responsible for biogas	Avfall Sverige AB	General information about feedstocks for the production of biogas.
31/8 -06	Peter Undén	Marketing manager	Svensk Biogas AB (Linköping)	Information about the biogas production in Linköping and the potential of biogas in Sweden.
7/9 -06	Gunnar Ingelman	Marketing manager	FordonsGas AB	General information regarding biogas as a vehicle fuel.
20/9 -06	Peter Boisen	Chairman	ENGVA (European Natural Gas Vehicle Association)	We were informed that no studies exist on the production of biogas in Europe on plant size level. Information regarding the outlook for biogas to emerge as a vehicle fuel in Europe.
23/9 -06	Bo Ramberg	Managing director	FordonsGas AB	General information regarding the potential of biogas as a vehicle fuel in Europe.
8/9 -06	Gunnel Klingberg	Responsible for legislations and EU related tasks	Avfall Sverige AB	Regarding the organisation of waste management organisations in Europe.
3/10 -06	Peder Barrling	Sales	Tekniska Verken i Linköping AB	Regarding biogas as a vehicle fuel. (At the RVF-conference)
3/10 -06	My Carlsson	Engineer	AnoxKaldnes	Sewage gas. (At the RVF-conference)
3/10 -06	Eric Zinn	Engineer/Consultant	SWECO	Planned biogas plants in Sweden. (At the RVF-conference).
9/10 -06	Anders Lingsten	Project leader	Svenskt Vatten AB	General information about sewage gas.
9/10 -06	Stefan Dahlgren	Technlology and safety manager	Sveska biogasföreningen	General info about biogas
11/10 -06	Michelle Ekman	Vehicle fuel manager	Svenska biogasföreningen	Information about production in Sweden

12/10 & 30/11 -06	Annika Koningen	Biogas manager	Svenska gasföreningen	Information about volumes of biogas produced in Sweden
12/10 -06	Kalle Svensson	-	HS Konsult AB	Information about volumes of biogas produced in Sweden
11/10 -06	Kerstin Forsén	Energy statistics	Statistiska Centralbyrån, SCB	Information about volumes of biogas produced in Sweden
12/10 -06	Anna Hjärne	Energy statistics	Statistiska Centralbyrån, SCB	Information about volumes of biogas produced in Sweden
12/10 -06	Christopher Maltin	IEA bioenergy contact person for the UK	Organic Power Ltd.	Regarding the production of biogas in the UK
12/10 -06	David Baxter	IEA Bioenergy contact person	European Commission - Joint Research Centre	Regarding the production of biogas in Europe
12/10 -06	Owe Jönsson	IEA Task 37 contact person	Svenskt gastekniskt centrum, SGC	Regarding the production of biogas in Europe
13/10 -06	Jens Bo Holm-Nielsen	IEA Task 37 contact person	Aalborg University	Regarding the production of biogas in Denmark
24/1 -07	Simona Negro	Researcher	Utrecht University	Information about the biogas situation in Germany and the Netherlands.
13/10 -06	Lars Kjolbye	Unit director	European Commission	Regarding biogas plants in Europe
16/10 -06	Mikael Szude	-	Statistiska Centralbyrån, SCB	Regarding landfill gas in Sweden and Europe
16/10 -06	Hans van Steen	Unit director	European Commission	Regarding the production of biogas in Europe
2/11 -06	Christian Azar	Professor	Chalmers University of Technology	On alternative fuels and the economic benefits of using biogas as a vehicle fuel.
16/10	Reinhard Reifenstuhl	-	German Association for Water, Wastewater and Waste	Sewage gas
16/10 -06	Diane Lescot	Report responsible	EurObserver, Paris	Regarding the sources of information used for the Observer reports.
16/10 -06	Thomas Rihm	Landfill gas responsible	Avfall Sverige AB	Regarding landfill gas in Sweden and Europe
17/10 -06	Claude Servais	-	Club Biogaz, France	Biogas production in France
17/10 -06	Hans C. Willumsen	Managing Director	LFG Konsult, Denmark	Regarding landfill gas in Europe
17/10 -06	Claudius da Costa Gomez	Managing Director	Fachverband Biogas, Germany	Regarding biogas production in Germany and Europe.
18/10 -06	Peter Weiland	IEA Task 37 contact person		Biogas in Germany.
19/10 -06	Göran Värmby	Project Manager	Business Region Göteborg	Regarding biogas in Sweden and Europe
25/10 -06	Per Forsberg		Läckeby Water Group AB	Regarding the supplier networks and their opinion regarding the development of the biogas market.

27/10 - 06	Cornelia Schoenlinner	Sales Assistant	Linde AG, Germany	Supplier networks
27/10 - 06	Kjell Axelsson	Sales Manager	Läckeby Water Group AB	Regarding the supplier networks and their opinion regarding the development of the biogas market.
27/10 - 06	Barbara Winkler	Sales plant construction	Schmack Biogas, Germany	Information about the biogas industry in Europe.
30/10 - 06	Joseph Barth	Managing director	European Compost Network, ECN, Germany	Information about the biogas production in Germany and Europe
30/11 - 06	Ludwig Dinkloh	Head of International Business	Schmack Biogas, Germany	Information about the biogas industry in Europe.
30/10 - 06	Harry Wiljan	Managing director	BTA, Germany	Information about the biogas industry and supplier networks in Europe.
21/11	Trevor Fletcher	Managing Director	The Hardstaff Group, UK	Information regarding biogas in the UK. (At the Eco-Tech Fair, Gothenburg)
30/11 - 06	Peter Knecht	-	Kompogas AG, Switzerland	Information about the biogas industry and supplier networks in Europe.
27/11 - 06	Chris Kovacs	-	Hungarian biogas association	Information about biogas in Hungary
29/11 - 06	Dieter Korz	Managing Director	Ros Roca Internacional, Spain	Regarding the biogas industry in Spain and Europe
15/12 - 06	Anders Johansson	Environment dept.	AB Volvo	Fuel consumption statistics
15/12 - 06	Mats Matsson	Statistics responsible	Bil Sweden AB	Fuel consumption statistics
19/1 -07	Dietrich Klein	Manager	Deutscher Bauernverband e.V.	Regarding alternative fuels in Germany.
19/1 -07	Heiki Donath	Manager	Deutche Biodiesel Gmbh&Co.	Regarding legislations for promoting RES in Germany
1/2 -07	Paul Hodson	Responsible for policies for the promotion of bio-fuels.	European Commission, Transport and Energy (TREN)	EU policies on bio-fuels and biogas.
2/2 -07	Kent Nyström	Managing Director	Svebio	On the role of AEBIOM for the promotion of biogas as a vehicle fuel. Mr. Nyström is the former president of the organisation.

Attended Conferences or Fairs:

Date	Name	Organizer	Location	Purpose
2/10 -06	"Biologisk behandling"	RVF / Avfall Sverige	Västerås, Sweden	Get an overview of the biogas situation in Sweden and meet "face-to-face" within the field.
21-23/11 -06	"Eco-Tech Scandinavia"	Natlikan	Gothenburg, Sweden	Meet professionals within the biogas and alternative fuel industry in Europe.
18-27/1 -07	"International Green Week"	Messe Berlin GmbH	Berlin, Germany	Get a better insight in the German biogas market and industry. Meet professionals from Europe within the field of biogas and alternative fuels.
1/2 -07	"Sustainable Energy Week"	European Commission	Brussels, Belgium	Get insights into the policy making in various European countries for the promotion of biogas.

Attended conference presentations, "Eco-Tech Scandinavia", Gothenburg:

Date	Name	Title/Position	Organisation	Title
21/11 -06	Leif Johansson	President and CEO	The Volvo Group	"Sustainable Innovations"
21/11 -06	Lena Ek	Committee of Industry, Research and Energy	European Parliament	"EU policy on research, industry and energy – how will it effect innovations and business operations?"
21/11 -06	Mike Scott	Writer/Journalist	Financial Times and New Energy Finance	"What drives sustainable innovation?"
21/11 -06	Lennart Billfalk	Senior Vice President	Vattenfall	"The role of global policies and new technology for sustainable development"
21/11 -06	Christian Kornevall	Director, Energy Efficiency in Buildings Project	World Business Council for Sustainable Development	"Sustainability and the Global Business"
21/11 -06	Peter Boisen	President	European Natural Gas Vehicle Association	"Biomethane for Vehicles - A European Overview"
21/11 -06	Pierre Hirtzberger	Project manager from Lille Metropole, France, for the EU-project BiogasMax	Lille Metropole, France	"Biogas as Vehicle Fuel Market Expansion to Air Quality 2020"
21/11 -06	Margareta Persson	Research Manager	Swedish Gas Centre (SGC)	"Exposé of New Technology in the Biogas Area - from Production to Utilization in Vehicle."
21/11 -06	Trevor Fletcher	Managing Director	The Hardstaff Group, UK	"The Dual Fuel Experience - Running a heavy duty truck fleet with the dual-fuel technique (LNG and CNG) - the Business Case, Technique and Economy."

21/11 - 06	Anders Hedenstedt	Managing Director	Göteborg Energi AB	“Biomethane as Business - Presentation of Göteborg Energi biomethane business and long-term strategy, the new up-grading plant and the plans for gasification plant for biomethane production.”
21/11 - 06	Alfons Schulte-Schulze Berndt	Managing Director	CarboTech Engineering GmbH, Germany	“Intelligent Utilization of Biogas – Upgrading and Adding to the Grid”
21/11 - 06	Anna Pettersson	Research Manager	Vattenfall Power Consultant AB	“LCNG-Study - Possibilities with LNG Supporting Supply of Methane as a Vehicle Fuel in Sweden”

Attended conference presentations, ”Biological treatment”, arranged by RVF, Västerås:

Date	Name	Title/Position	Organisation	Title/Subject
3/10 -06	Per Nilsson	Managing director	Vafab Miljö	Biogas in Västerås – the Växtkraft-project
3/10 -06	Leif Lundin	Engineer/Consultant	CarlBro	Regarding biogas projects CarlBro has been involved in.
3/10 -06	Hanna Hellström	Responsible for biogas	Avfall Sverige AB	About biological treatment in Sweden.
3/10 -06	Anna Turesson	Engineer	Vafab Miljö	The Växkraft-project in Västerås.
3/10 -06	Jörgen Leander	Engineer/Consultant	CarlBro	About different sources for feedstocks related to the production of biogas.
3/10 -06	Peder Barrling	Sales	Tekniska Verken I Linköping AB	“Bioavfall – rollen som säljare”
3/10 -06	My Carlsson	Engineer	AnoxKaldnes	Anaerobic digestion
3/10 -06	Eric Zinn	Engineer/Consultant	SWECO	Biological treatment in South Africa
3/10 -06	Maria Eriksson	Engineer	Allren AB	Biological treatment

Attended conference presentations, “Sustainable Energy Week”, Brussels:

Date	Name	Title/Position	Organisation	Title/Subject
1/2 -07	Ralph Goldmann	Division Manager	Energy Agency Berlin	“Case study Germany: Private Public Partnerships for European Regions”
1/2 -07	Christiane Egger	Vice President, policy maker	Fedarane, Austrian Energy Agency	“Case study Austria: Making Sustainable Energy a Priority”
1/2 -07	Juan Manuel Revuelta	Director-General	Valencian Region Delegation in Brussels	“Case study Spain: Energy Solutions Strategy of Valencia.”

Attended dissertations:

Date	Name	Title	Organisation	University
15/6	Mats Williander	On Green Innovation Inertia	Volvo Cars	Chalmers University of Technology

Appendix D – Production of Biogas in Europe

		2002	2003	2004	2005
Spain	ktoe	168	257	295	317
	% Heavy Duty Transp.	2%	3%	3%	3%
Austria	ktoe	59	38	42	45
	% Heavy Duty Transp.	2%	1%	1%	1%
Germany	ktoe	659	1229	1294	1594,00
	% Heavy Duty Transp.	4%	8%	8%	10%
Sweden	ktoe	147	119	105	115,80
	% Heavy Duty Transp.	10%	8%	7%	8%
UK	ktoe	1076	1253	1491	1783
	% Heavy Duty Transp.	11%	12%	15%	18%
Italy	ktoe	155	155	336	377
	% Heavy Duty Transp.	1%	1%	3%	3%
Netherlands	ktoe	149	109	126	126
	% Heavy Duty Transp.	4%	3%	4%	4%
France	ktoe	200	200	207	209
	% Heavy Duty Transp.	1%	1%	1%	1%
Denmark	ktoe	62	83	89	92
	% Heavy Duty Transp.	5%	6%	7%	7%
Belgium	ktoe	56	42	73,8	74
	% Heavy Duty Transp.	2%	1%	2%	2%
Ireland	ktoe	28	19	29,9	35
	% Heavy Duty Transp.	3%	2%	3%	4%
Luxembourg	ktoe	2	4	5	7
	% Heavy Duty Transp.	0,3%	0,6%	0,7%	1,0%
Finland	ktoe	18	16	26,5	27
	% Heavy Duty Transp.	2%	1%	2%	2%
Portugal	ktoe	76	76	4,5	10
	% Heavy Duty Transp.	3%	3%	0,2%	0,4%
Slovenia	ktoe	-	6	6,6	7
	% Heavy Duty Transp.	-	1%	1%	2%
Czech Republic	ktoe		41	50,2	56
	% Heavy Duty Transp	-	2%	2%	2%
Hungary	ktoe	-	2	3,5	4
	% Heavy Duty Transp.	-	0,1%	0,2%	0,2%
Poland	ktoe	63	35	45,4	51
	% Heavy Duty Transp.	0,7%	0,4%	0,5%	0,6%
Slovakia	ktoe	-	3	5,90	5,90
	% Heavy Duty Transp.	-	0%	0%	0%
Greece	ktoe	42	42	36	36
	% Heavy Duty Transp.	3%	3%	3%	3%
Europe Total	ktoe	2960	3729	4273	4970
	% Heavy Duty Transp.	3%	4%	5%	6%

Source: EurObserver (2003, 2004, 2005, 2006)

Appendix E – Biogas Producing Plants in Europe

Sweden

Category	Number of plants	Production (ktoe)
Landfills	72[22]	43,8
Sewage waste plants	135[23]	69.7
Industrial sewage plants	8[24]	
Centralized Biogas plants	15[25]	10.2
Farmscale biogas plants	6[26]	0.5
Total	236	124.2

Same reference for number of plants and corresponding production figure.

Denmark

Category	Number of plants[27]	Production (ktoe)
Sewage waste plants	64	20.8
Landfills	25	10.6
Industrial sewage plants	5	3.4
Centralized Biogas plants	20	36.5
Farmscale biogas plants	60	14.9
Total	174	86.2

Same reference for number of plants and corresponding production figure.

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[22] RVF, (2003)

[23] Berglund, (2006)

[24] Lior International, (2006)

[25] RVF, (2003)

[26] AD-Nett, (2005)

[27] Holm-Nielsen and Seadi, (2006)

Germany

Category	Number of plants	Production (kToe) [28]
Landfills	182[29]	573.2
Sewage waste plants	~925 (500)[30]	369.8
Industrial sewage plants	91[31]	
Centralized Biogas plants	52[32]	651.4
Farmscale biogas plants	~3500[33]	
Total	~4750	1594.4

Austria

Category	Number of plants[34]	Production (ktoe)
Landfills	62	23,2-51,6
Sewage waste plants	134	38,7- 51,6
Industrial sewage plants	25	4,6 – 7,2
Centralized Biogas plants	15	7,7- 9,3
Farmscale biogas plants	~350	62,4- 93,9
Total	~586	137-214

Same reference for number of plants and corresponding production figure.

Switzerland

Category	Number of plants	Production (ktoe)
Landfills	7[35], (48*)[36]	~17,2
Sewage waste plants	57[37],	3,8
Industrial sewage plants	23[38]	3,3
Centralized Biogas plants	12[39]	4,5
Farmscale biogas plants	69[40]	2,2
Total	209	32.8

* Landfill sites in Switzerland where gas is collected but not always used for energy purposes.

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[28] EurObserver, (2006)
[29] Willumsen, (2004)
[30] Durth, et al., (2005)
[31] Lior International, (2006)
[32] IEA Task 37, (2006)
[33] Weiland, (2006)
[34] Braun, (2006)
[35] Willumsen, (2004)
[36] Umweltbundesamt, (2006)
[37] Bundesamtes für Energie, (2004)
[38] Ibid.
[39] Ibid.
[40] Ibid.

The UK

Category	Number of plants	Production (ktoe)
Landfills	365[41]	1617.6
Sewage waste plants	200[42], 90[43]	165
Industrial sewage plants	26[44]	
Centralized Biogas plants	3[45]	-
Farmscale biogas plants	3[46]	-
Total	487 - 597	1782

France

Category	Number of plants	Production (ktoe)
Landfills	22[47] - 26[48]	129
Sewage waste plants	83 - 143[49]	77
Industrial sewage plants	103[50]	
Centralized Biogas plants	2[51]	3
Farmscale biogas plants	7[52]	
Total	217 - 281	209

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[41] REA, (2006a)
[42] Lior International, (2006)
[43] REA, (2006b)
[44] Lior International, (2006)
[45] REA, (2006b)
[46] Ibid.
[47] Gaz de France and ADEME, (2005)
[48] Willumsen, (2004)
[49] Gaz de France and ADEME, (2005)
[50] Ibid.
[51] IEA Task 37, (2006)
[52] AD-Nett, (2005)

Spain

Category	Number of plants	Production (ktoe)
Landfills	14[53]	236.5
Sewage waste plants	-	56.8
Industrial sewage plants	27[54]	
Centralized Biogas plants	23 + 4*[55]	23.6
Farmscale biogas plants	-	
Total	68	316.9

* Under construction or in planning stage in November, 2005

Italy

Category	Number of plants	Production (ktoe)
Landfills	135[56] - 150[57]	334.1
Sewage waste plants	4[58]	0.4
Industrial sewage plants	38[59]	
Centralized Biogas plants	8[60]	42
Farmscale biogas plants	67[61]	
Total	252 - 267	376.5

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[53] Willumsen, (2004)
[54] Lior International, (2006)
[55] Korz, (2005)
[56] Willumsen, (2004)
[57] Methane to Markets Partnership Landfill Subcommittee, (2003)
[58] EUBIONET, (2003)
[59] Lior International, (2006)
[60] IEA Task 37, (2006)
[61] Methane to Markets Partnership Landfill Subcommittee, (2003)

The Netherlands

Category	Number of plants	Production (ktoe)[62]
Landfills	47[63]	48.7
Sewage waste plants	-	48.6
Industrial sewage plants	84[64]	
Centralized Biogas plants	4[65]	28.9
Farmscale biogas plants	(15)[66], 20 - 25[67]	
Total	150 - 160	126.2

Belgium

Category	Number of plants	Production (ktoe)
Landfills	7[68]	68[69]
Sewage waste plants	9[70]	9.7
Industrial sewage plants	4[71]	
Centralized Biogas plants	-	
Farmscale biogas plants	5[72]	

Portugal

Category	Number of plants	Production (ktoe)
Landfills	1[73]	-
Sewage waste plants	-	-
Industrial sewage plants	3[74]	-
Centralized Biogas plants	-	10[75]
Farmscale biogas plants	100[76]	
Total	104	10

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[62] EurObserver, (2006)
[63] Willumsen, (2004)
[64] Lior International, (2006)
[65] Neeft, (2005)
[66] AD-Nett, (2005)
[67] Neeft, (2006)
[68] The Federal Administration, (2005)
[69] Ibid.
[70] Ibid.
[71] Ibid.
[72] AD-Nett, (2005)
[73] Willumsen, (2004)
[74] Lior International, (2006)
[75] EurObserver, (2006)
[76] AD-Nett, (2005)

Finland

Category	Number of plants	Production (ktoe)[77]
Landfills	14[78] - 33[79]	16.6
Sewage waste plants	15[80]	9.9
Industrial sewage plants	3[81]	
Centralized Biogas plants	3[82]	-
Farmscale biogas plants	4[83]	-
Total	39 - 58	26.5

Norway

Category	Number of plants	Production (ktoe)
Landfills	30[84]	-
Sewage waste plants	17[85]	-
Industrial sewage plants	5[86]	-
Centralized Biogas plants	15[87]	-
Farmscale biogas plants	-	-
Total	67	-

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[77] EurObserver, (2006)
[78] Willumsen, (2004)
[79] Jormanainen, (2006)
[80] Ibid.
[81] Lior International, (2006)
[82] Jormanainen, (2006)
[83] Ibid.
[84] Willumsen, (2004)
[85] Lior International, (2006)
[86] Ibid.
[87] Avfall Norge, (2006)

Poland

Category	Number of plants	Production (ktoe)[88]
Landfills	19[89] - 33[90]	25.1
Sewage waste plants	35[91] - 51[92]	25.3
Industrial sewage plants	-	
Centralized Biogas plants	2[93]	0.3
Farmscale biogas plants	10[94] - 15[95]	
Total	66	50.7

Czech Republic

Category	Number of plants	Production (ktoe)[96]
Landfills	6[97]	21.5
Sewage waste plants	12[98], 20 - 30[99]	31.4
Industrial sewage plants	-	
Centralized Biogas plants	0[100]	-
Farmscale biogas plants	10[101], 11[102]	2.8
Total	28 - 47	55.8

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[88] EurObserver, (2006)
[89] Willumsen, (2004)
[90] Swiss Business Hub, (2005)
[91] Nilsson, et al., (2006)
[92] Swiss Business Hub, (2005)
[93] IEA Task 37, (2006)
[94] Nilsson, et al., (2006)
[95] AD-Nett, (2005)
[96] EurObserver, (2006)
[97] Willumsen, (2004)
[98] European Compost Network, (2006)
[99] IUSE Frauenhofer Institut, (2003)
[100] Slejška, et al., (2005)
[101] AD-Nett, (2005)
[102] IUSE Frauenhofer Institut, (2003)

Hungary

Category	Number of plants[103]	Production (ktoe)[104]
Landfills	-	0.8
Sewage waste plants	10	2.9
Industrial sewage plants		
Centralized Biogas plants	1	0.2
Farmscale biogas plants	0	0
Total	11	3.9

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[103] Máté, (2006)

[104] EurObserver, (2006)

Appendix F – Policies in Europe

In this appendix, a presentation of the country's policies related to biogas is presented. However, many countries do not have any specific policies targeted towards the production of biogas. In these cases, the policies that are relevant are the general policies for the promotion of RES (Renewable Energy Sources), of which biogas is included. The European Union's general policy towards RES consists of various targets that the countries are committed to fulfil. These targets are presented below, together with the European Commission's suggestion for new targets presented in January 2007. These targets have not yet been accepted by the European Parliament. What kind of governmental policy instruments that are used for reaching these targets are up to the individual member state to decide. Most countries use some kind of feed-in tariffs for energy produced from RES. Even though feed-in tariffs are proven to be an effective way of promoting the use of RES and biogas, this is not always the case. The success of a feed-in tariff based system is, obviously, dependent on what the feed-in tariff actually is set to be and also under what period of time it is guaranteed.

- European Commission's suggestions on new binding targets for the European Union targets (European Commission, 2007b):
    - 20 % of the total energy mix should be sourced to renewable energy by 2020.
    - 10 % share of biofuels by 2020.
- European Union directive 2003/30/EC on the use of biofuels currently in force
    - 5.75 %[105] of all petrol and diesel fuels for transport 2010.

The European Union's directives for the handling of biodegradable waste are also important to consider, since waste is an important feedstock for the production of biogas. These directives are therefore also presented below.

- European Union directive 1999/31/EG on the landfill of waste (European Parliament, 1999):

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[105] 5.75 % is a reference value related to the total energy content of the consumed diesel and petrol for transport.

- The amount of biologically degradable urban waste that is landfilled should in 2016 be reduced to 35 % of the amount landfilled in 1995.[106]
- Landfill gas should be collected from landfills that receive organic waste.
- The landfill gas should when possible be collected and used. If the valorisation of the gas is not possible, it should be flared.

Austria

Tax	-
Financial subsidies	-
Biogas in the national gas grid	Yes.
Pricing of energy from biogas	Feed in tariffs for electricity produced from biogas. (10.3-16.5 €ct/kWh) [107] However, new restrictions on the number of plants that are guaranteed these feed in tariffs has been introduced.[108]
Standards for biogas	-
Waste policies	Legal obligation to collect biodegradable waste separately. This waste should then be biologically treated. This means that biodegradable waste put on landfills must first be biologically treated.[109]

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[106] This target is fulfilled in a step by step procedure, where 75 % the year of 2006, 50 % in 2009 and finally, 35 % in 2016. Countries that landfilled more than 80 of their urban waste can postpone the target 4 years.

[107] Braun, (2006)

[108] Jönsson, (2007)

[109] European Commission, (2005b)

Belgium

Tax	-
Financial subsidies	Yes. In total 7 biogas projects of a total project cost of € 8 977164 have been granted subsidies of a total value of € 1 339 691.[110]
Biogas in the national gas grid	No.
Pricing of energy from biogas	A complex system that includes both minimum prices that are guaranteed for 13 years and certificates. However, the approach for the promotion of energy from biogas depends upon the federal regions and is therefore not the same for the entire Belgium.[111] Flanders and Wallonia has introduced a quota obligation on the amount of energy that should be produced from RES.[112]
Standards for biogas	No.
Waste policies	Depends on the different regions. The Flemish region has banned the landfill of unsorted household waste, waste collected for recovery and combustible waste (with TOC of more than 6 %). The Walloon and the Brussels regions have not come as far as the Flemish region regarding the fulfilment of the European Union targets.[113]

Denmark

Tax	Heat production exempted from energy and CO_2-taxes.[114]
Financial subsidies	Subsidies for biogas related investments are being reduced and approaching zero.[115]
Biogas in the national gas grid	No obligation for natural gas distributors to inject biogas in the gas grid.
Pricing of energy from biogas	Feed-in tariffs.[116]
Standards for biogas	No standards for biogas.[117]
Waste policies	The amount of biodegradable municipal waste going to landfills has traditionally been low. In 1995, less that 10 % of this waste was landfilled. It is forbidden to landfill waste that is suitable for incineration.[118]

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[110] The Federal Administration, (2005)
[111] Ibid.
[112] European Commission, (2005c)
[113] European Commission, (2005b)
[114] Negro, et al., (2007)
[115] Holm-Nielsen and Seadi, (2006)
[116] Ibid.
[117] The Regional Energy Agency for Catalonia (ICAEN), et al., (2005)
[118] European Commission, (2005b)

Finland

Tax	Energy tax exemption for electricity produced from RES.[119]
Financial subsidies	Investment incentives that includes the financing of up to 30 % of investment costs. [120]
Biogas in the national gas grid	No.
Pricing of energy from biogas	Tax incentives and investment funds are the only incentives. No feed-in tariffs or green certificates.[121]
Standards for biogas	No.
Waste policies	-

France

Tax	Biogas as a vehicle fuel is exempted from general fossil fuels taxes.[122]
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed in tariffs for electricity produced from biogas.[123]
Standards for biogas	No.
Waste policies	France is not expected to reach the target of 35 % in 2016 (see introduction of appendix). The main strategy of reaching the target is recycling and incineration.[124]

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[119] European Commission, (2005c)
[120] Ibid.
[121] Ibid.
[122] Hitzberger, (2006)
[123] Ibid.
[124] European Commission, (2005b)

Germany

Tax	Biogas is exempted from normal fossil fuel taxes.
Financial subsidies	Access to long term low interest loans.[125]
Biogas in the national gas grid	No obligation for natural gas distributors to inject biogas in the gas grid.
Pricing of energy from biogas	Feed-in tariffs for the production of electricity.[126]
Standards for biogas	No national standard for biogas as a vehicle fuel.[127] National standard for injected biogas into the national gas grid.[128]
Waste policies	Biodegradable municipal waste is separately collected and treated. Landfills are only allowed to receive municipal waste that has been biologically treated or incinerated. [129]

Greece

Tax	-
Financial subsidies	Yes. Up to 40 % of investment. [130]
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed-in tariffs guaranteed for 10 years for electricity produced from biogas. [131]
Standards for biogas	No.
Waste policies	Will not be able to reach the European Union's target on the reduction of biodegradable waste being landfilled. Greece has postponed the 35 % target until 2020. [132]

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[125] Gomez, (2006a)
[126] Negro and Hekkert, (2006b)
[127] Jönsson, (2006)
[128] Weiland, (2006)
[129] European Commission, (2005b)
[130] European Commission, (2005c)
[131] Ibid.
[132] European Commission, (2005b)

Ireland

Tax	-
Financial subsidies	Tax incentives for the investments in RES.[133]
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed-in tariffs.[134]
Standards for biogas	No.
Waste policies	-

Italy

Tax	-
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Quota obligation of RES in energy mix supplied by distributors. Green certificates.[135]
Standards for biogas	No.
Waste policies	Italy has decided to use economic measures, e.g. an “eco-tax”, for the reduction of organic waste being landfilled. This will increase the costs of landfilling and therefore also promote other alternatives. [136]

The Netherlands

Tax	No.[137]
Financial subsidies	Fiscal incentives on investments in RES are available.[138]
Biogas in the national gas grid	No obligation for natural gas distributors to inject biogas in the gas grid.
Pricing of energy from biogas	Feed-in tariffs guaranteed for 10 years.
Standards for biogas	No.[139]
Waste policies	Most municipal waste is incinerated. The landfilling of separately collected biodegradable waste is forbidden.[140]

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[133] European Commission, (2005c)

[134] Ibid.

[135] Ibid.

[136] European Commission, (2005b)

[137] Negro, (2007)

[138] European Commission, (2005c)

[139] The Regional Energy Agency for Catalonia (ICAEN), et al., (2005)

Portugal

Tax	-
Financial subsidies	Investment subsidies up to 40 % of investment for RES.[141]
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed-in tariffs.[142]
Standards for biogas	No.
Waste policies	Approximately 90 % of the municipal waste was landfilled in 1995. However, Portugal is still aiming at fulfilling the targets set by the European Union, mainly through the promotion of back yard composting and incineration.[143]

Spain

Tax	Tax incentives are available.[144]
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Electricity producers can choose from a fixed feed-in tariff or premium put on top of the spot energy price.[145] The premium is guaranteed for the entire life span of the RES.
Standards for biogas	No.
Waste policies	-

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[140] European Commission, (2005b)
[141] European Commission, (2005c)
[142] Ibid.
[143] Ibid.
[144] Ibid.
[145] Ibid.

Sweden

Tax	Biogas is exempted from CO_2-tax and energy that is applied on fossil fuels.[146]
Financial subsidies	KLIMP (National Climate Investment Programme) helps municipalities with the financing of biogas plants. Since its introduction in 2002, SEK 1.24 billion has been allocated to various projects related to the reduction of greenhouse gases.[147] The agricultural development programme can help farmers with the financing of farmscale biogas plants. However, this subsidy is not often applied for biogas projects.[148]
Biogas in the national gas grid	There is no obligation for natural gas distributors to inject biogas in the gas grid, but this is done by several biogas producers and energy distributors.
Pricing of energy from biogas	Green certificates for the production of electricity.[149]
Standards for biogas	National standard for biogas as a vehicle fuel.[150]
Waste policies	Since 2005, it is forbidden to landfill combustible waste and organic waste.[151] Less than 5 % of the municipal waste is currently being landfilled in Sweden. [152]

UK

Tax	Tax exemption for energy produced from biogas. The tax that is exempted is the Climate Change Levy.
Financial subsidies	-
Biogas in the national gas grid	No. Biogas generally used at for CHP.
Pricing of energy from biogas	Green certificates (Renewable Obligation Certificates, ROC)[153]
Standards for biogas	No.
Waste policies	The UK have postponed the European Union's target by 4 years.[154] 75 % of the municipal waste was sent to landfills in 2003.[155]

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[146] Lantz, et al., (2007)
[147] Naturvårdsverket, (2006b)
[148] Lantz, et al., (2007)
[149] European Commission, (2005c)
[150] Jönsson, (2006)
[151] European Commission, (2005b)
[152] Avfall Sverige, (2007)
[153] European Commission, (2005c)
[154] European Commission, (2005b)
[155] National Audit Office (UK), (2006)

Czech Republic

Tax	Tax reductions are used as a complementary policy tool for the promotion of RES.[156]
Financial subsidies	Investment grants can be obtained, corresponding up to 30 % of the investment cost. Low interest loans also available. These policy instruments are focused on electricity production from RES in general. [157]
Biogas in the national gas grid	No.
Pricing of energy from biogas	A combination of green certificates and an obligation for electricity suppliers to provide a certain amount of energy produced from RES. Biogas is guaranteed a minimum price of 2400 CSK/kWh. [158]
Standards for biogas	No.
Waste policies	-

Switzerland

Tax	Tax reductions for gas distributed through the national gas grid thanks to the natural gas industry's voluntary commitment to inject biogas in the national gas grid.[159] Biomethane as vehicle fuel is exempted from fuel tax.[160]
Financial subsidies	-
Biogas in the national gas grid	Yes. Injected in the natural gas grid. This is a voluntary commitment by the gas distributors.
Pricing of energy from biogas	Feed in tariffs for the production of electricity (18-22 €cts / kWh). [161]
Standards for biogas	A standard exists for biogas injected in the national gas grid.[162]
Waste policies	Even though Switzerland is not affected by the European Union's directives regarding the handling of waste, they are one of the countries in Europe with the lowest amount of municipal waste per inhabitant being landfilled.[163]

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[156] European Commission, (2005c)

[157] The Czech Republic, et al., (2005)

[158] Ibid.

[159] Jönsson, (2007)

[160] National Society for Clean Air and Environmental Protection (NSCA), (2006)

[161] Wellinger, (2006)

[162] The Regional Energy Agency for Catalonia (ICAEN), et al., (2005)

[163] Eurostat, (2007)

Poland

Tax	No tax incentives.
Financial subsidies	No.
Biogas in the national gas grid	No.
Pricing of energy from biogas	Green certificates. The “Energy Act” obliges electricity suppliers to include 9 % of bio-energy in their energy mix. [164]
Standards for biogas	No.
Waste policies	-
Further comments	No coherent strategy exists for the promotion of bioenergy in Poland, other than targets that are set in line with EU directives.[165] Nevertheless, specific policy instruments on how these targets should be met do not exist. The biogas valorised in the Poland generally comes from landfills or sewage waste stations. Even though 10 farmscale plants have been constructed, most of them are not in operation due to economical and/or technical problems, [166] which can be regarded as a result of the lack of incentives set by the government for the promotion of renewable energy sources, e.g. biogas.

Estonia

Tax	-
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed-in tariffs for electricity produced from biogas. However, the feed-in tariffs are considered as low and are only guaranteed for 7 years, and no longer than 2015. [167]
Standards for biogas	No.
Waste policies	-

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[164] Nilsson, et al., (2006)
[165] Ibid.
[166] Ibid.
[167] European Commission, (2005c)

Hungary

Tax	-
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed-in tariffs for electricity produced from RES (6 - 6.8 €ct/kWh). [168]
Standards for biogas	No.
Waste policies	Have introduced a tax on waste being landfilled. 50 % of the waste being landfilled by 2007 should be pre-treated, either biologically, mechanically or chemically.

Latvia

Tax	-
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed-in tariffs.
Standards for biogas	No.
Waste policies	-
Further comments	The government policy towards RES is characterized by frequent changes which results in high investment uncertainty. [169]

Lithuania

Tax	-
Financial subsidies	Different investment programmes related to RES. These investment programmes are limited to companies registered in Lithuania. [170]
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed-in tariffs.[171]
Standards for biogas	No.
Waste policies	-

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[168] Ibid.
[169] Ibid.
[170] Ibid.
[171] Ibid.

Slovakia

Tax	Tax incentives exist.
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed-in tariffs. However, the tariffs are unclear and the time-span of the tariffs is also not specified.
Standards for biogas	No.
Waste policies	-
Further comments	According to the European Commission, very little is made for the promotion of RES. Even though feed-in tariffs and tax incentives exist, they are not sufficient for the promotion of biogas.[172]

Slovenia

Tax	Tax incentives exist for the promotion of RES.[173]
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Feed-in tariffs.[174]
Standards for biogas	No.
Waste policies	-

Bulgaria

Tax	-
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Green certificate system has been proposed, but has not been introduced yet.[175]
Standards for biogas	No.
Waste policies	-

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[172] Ibid.
[173] Ibid.
[174] Ibid.
[175] Ibid.

Romania

Tax	-
Financial subsidies	-
Biogas in the national gas grid	No.
Pricing of energy from biogas	Modest feed-in tariffs.[176]
Standards for biogas	No.
Waste policies	-

Norway

Tax	**-**
Financial subsidies	-
Biogas in the national gas grid	-
Pricing of energy from biogas	-
Standards for biogas	-
Waste policies	-

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[176] Ibid.

Appendix G – IEA and EurObserver comparison

	EurObserver		IEA Statistics		
	kToe (2005)	kToe (2003)	kToe	Gwh	TJ
UK	1783	1253	1128,8	13125,8	47253
Germany	1594	1229	915,5	10645,6	38324
France	209	344	189,8	2207,2	7946
Spain	317	257	256,6	2984,2	10743
Italien	377	201	255,4	2969,7	10691
Netherlands	126	109	128,5	1494,2	5379
Sweden	105	119	112,0	1302,8	4690
Portugal	10	76	0,8	9,7	35
Denmark	92	83	85,5	993,9	3578
Austria	45	38	42,6	495,6	1784
Belgium	74	42	51,5	599,2	2157
Greece	36	32	36,0	418,6	1507
Ireland	35	19	25,4	295,0	1062
Finland	27	16	19,9	231,7	834
Luxenburg	7	4	4,1	48,1	173
Polen	51	35	38,9	452,2	1628
Slovenia	7	6	0,0	0,0	
Slovakia	6	3	3,8	43,6	157
Hungary	4	2	4,9	57,2	206
Tjeck Rep.	56	41	41,3	480,3	1729
Switzerland	-	-	59,0	685,8	2469
Norway	-	-	25,6	298,1	1073
Total	4961	3909	3426,1	39838,3	143418

Source: EurObserver (2006); IEA, (2003)

Appendix H – Definition of the EEG-law

The EEG, or the Renewable Energy Sources Act was adopted in the beginning of year 2000 in Germany. To support wind, photovoltaic and biomass electricity production grid operators was enforced to purchase the electricity from these renewable sources at an ensured and consistent price over a 20 year period. The ensured purchase price was differentiated according to energy source and depending on the size and capacity of the installation. For example, operators of plants with a capacity smaller than 500 kW, was guaranteed that the produced electricity would be purchased for 9.5 cents € /kWh. As a result, investments in renewable energy became more secure, and were stimulated to be done early since the guaranteed price was set to decline each year. In 2004, the EEG was renewed which implied improved the conditions for biogas electricity and the also started to include biogas produced at landfills and sewage stations. Another addition was that small farm scale biogas plants with capacity of 150 kW or less, was guaranteed compensation at 11.5 cents € /kWh. Also a set of payment bonuses was added to stimulate innovative technologies and usage of heat. The current conditions is as follow:

Capacity 0 - 150 kW guaranteed 11.5 cents € /kWh

Capacity 150 - 500 kW guaranteed 10.2 cents € /kWh

Capacity 150 - 500 kW guaranteed 11.5 cents € /kWh

Capacity 5MW - 20 MW guaranteed 11.5 cents € /kWh

Bonus for innovative technologies

To promote innovative technologies, an additional 2.0 cents € /kWh is guaranteed for power produced in combination with technologies such as cogeneration or by bio-methane ugradiing

Bonus for regenerative raw materials

For digestion of agricultural by- products such as manure extra payments for up to 500 kW capacity, increased by 6.0 cents/kWh and for up to 5 MW by 4.0 cents/kWh.

Bonus for CHP power

If power and heat are produced togehter additional 2.0 cents/kWh is guaranteed

Bonus for innovative technologies

These purchase prices and guarantees are given for 20 years. The rates will decrease at rate of 1.5 % annually.

Source: (BMU, 2006)

Appendix I – Catching Up Forecast

Production of biogas in ktoe and the corresponding share of heavy duty vehicles fuel consumption (%).

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Austria	59	38	42	45	51	58	66	75	84	96	108	122	139	157
	2%	1%	1%	1%	2%	2%	2%	2%	3%	3%	3%	4%	4%	5%
Belgium	56	42	73,8	74	82	90	100	110	122	135	149	165	182	201
	2%	1%	2%	2%	3%	3%	3%	4%	4%	4%	5%	5%	6%	6%
Czech Republic	-	41	50,2	56	63	72	81	92	105	119	135	153	174	197
	-	2%	2%	2%	3%	3%	4%	4%	5%	5%	6%	7%	8%	9%
Denmark	62	83	89	92	95	97	100	102	105	108	110	113	116	119
	5%	6%	7%	7%	7%	7%	7%	8%	8%	8%	8%	8%	9%	9%
Italy	155	155	336	377	420	468	522	582	649	723	807	899	1003	1118
	1%	1%	3%	3%	3%	4%	4%	5%	5%	6%	6%	7%	8%	9%
Netherlands	149	109	126	126	138	151	166	182	199	218	239	262	287	314
	4%	3%	4%	4%	4%	4%	5%	5%	6%	6%	7%	8%	8%	9%
UK	1076	1253	1491	1783	1833	1885	1938	1993	2049	2107	2167	2228	2291	2356
	11%	12%	15%	18%	18%	19%	19%	20%	20%	21%	21%	22%	23%	23%
Spain	168	257	295	317	348	383	421	463	509	560	615	677	744	818
	2%	3%	3%	3%	4%	4%	4%	5%	5%	6%	6%	7%	8%	8%
Ireland	28	19	29,9	35	38	41	44	48	52	56	61	66	72	78
	3%	2%	3%	4%	4%	4%	5%	5%	5%	6%	6%	7%	7%	8%
LUX	2	4	5	7	7	7	7	8	8	8	8	8	9	9
	0,3%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Finland	18	16	26,5	27	30	35	40	45	52	59	68	77	88	101
	2%	1%	2%	2%	3%	3%	4%	4%	5%	5%	6%	7%	8%	9%
France	200	200	207	209	248	295	350	415	493	585	695	825	980	1163
	1%	1%	1%	1%	1%	2%	2%	2%	3%	3%	4%	5%	5%	7%
Portugal	76	76	4,5	10	14	18	25	33	45	61	82	111	150	202
	3%	3%	0%	0%	1%	1%	1%	1%	2%	2%	3%	4%	6%	8%
Slovenia	-	6	6,6	7	8	10	11	14	16	19	23	28	33	39
	-	1%	1%	2%	2%	2%	3%	3%	4%	4%	5%	6%	7%	9%
Sweden	147	119	105	116	121	125	131	136	142	147	153	160	166	173
	10%	8%	7%	8%	8%	9%	9%	9%	10%	10%	10%	11%	11%	12%
Hungary	-	2	3,5	4	6	8	12	18	27	40	60	89	132	195
	-	0,1%	0,2%	0,2%	0,3%	0,4%	0,6%	0,8%	1,2%	1,8%	2,7%	4,0%	5,9%	8,7%
Poland	63	35	45,4	51	66	87	113	148	193	253	330	432	565	738
	1%	0%	1%	1%	1%	1%	1%	2%	2%	3%	4%	5%	7%	9%
Slovakia	-	3	5,90	5,90	8	10	14	19	25	33	44	59	78	104
	-	0,3%	0,5%	0,5%	0,7%	0,9%	1,2%	1,6%	2,1%	2,8%	3,7%	4,9%	6,5%	8,7%
Greece	42	42	36	36	43	51	61	73	88	105	125	149	178	213
	3%	3%	3%	3%	3%	4%	5%	6%	7%	8%	9%	11%	13%	16%
Germany	659	1229	1294	1594	1737	1892	2061	2245	2446	2665	2903	3162	3445	3753
	4%	8%	8%	10%	11%	12%	13%	15%	16%	17%	19%	21%	22%	24%
Total	2960	3729	4273	4970	5355	5784	6263	6801	7408	8097	8882	9785	10829	12048
	3%	4%	5%	6%	6%	7%	7%	8%	9%	10%	10%	12%	13%	14%

Appendix J – Feed-In Tariff Forecast

Production of biogas in ktoe and the corresponding share of heavy duty vehicles fuel consumption (%).

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Austria	59	38	42	45	55	67	81	97	118	143	173	209	253	307
	2%	1%	1%	1%	2%	2%	3%	3%	4%	5%	6%	7%	8%	10%
Spain	168	257	295	317	377	449	535	637	759	904	1076	1282	1527	1818
	2%	3%	3%	3%	4%	5%	6%	7%	8%	9%	11%	13%	16%	19%
Germany	659	1229	1294	1594	1789	2043	2374	2803	3361	3966	4722	5477	6158	6940
	4%	8%	8%	10%	12%	13%	15%	18%	22%	26%	31%	36%	40%	45%
Sweden	147	119	105	115,80	137	161	190	224	265	312	368	434	512	604,52
	10%	8%	7%	8%	9%	11%	13%	15%	18%	21%	25%	30%	35%	41%
UK	1076	1253	1491	1783	2016	2280	2578	2915	3297	3728	4216	4767	5391	6097
	11%	12%	15%	18%	20%	22%	25%	29%	32%	37%	42%	47%	53%	60%
Italy	155	155	336	377	454	548	661	797	961	1159	1398	1686	2033	2453
	1%	1%	3%	3%	4%	4%	5%	6%	7%	9%	11%	13%	16%	19%
Netherlands	149	109	126	126	151	182	218	262	315	378	453	544	653	783,86
	4%	3%	4%	4%	4%	5%	6%	8%	9%	11%	13%	16%	19%	23%
France	200	200	207	209	255	312	381	465	568	693	847	1034	1263	1543
	1%	1%	1%	1%	1%	2%	2%	3%	3%	4%	5%	6%	7%	9%
Denmark	62	83	89	92	108	125	146	170	198	231	269	314	366	426,29
	5%	6%	7%	7%	8%	9%	11%	13%	15%	17%	20%	23%	27%	31%
Belgium	56	42	73,8	74	89	107	129	155	186	224	270	325	391	470
	2%	1%	2%	2%	3%	3%	4%	5%	6%	7%	9%	10%	12%	15%
Ireland	28	19	29,9	35	42	50	60	72	86	103	123	147	176	211
	3%	2%	3%	4%	4%	5%	6%	7%	9%	11%	13%	15%	18%	22%
Luxemb.	2	4	5	7	8	9	11	13	15	17	20	24	28	33
	0,3%	0,6%	0,7%	1,0%	1,1%	1,3%	1,6%	1,8%	2,2%	2,5%	3,0%	3,5%	4,1%	4,8%
Finland	18	16	26,5	27	32	39	47	57	70	84	102	124	151	183
	2%	1%	2%	2%	3%	3%	4%	5%	6%	8%	9%	11%	13%	16%
Portugal	76	76	4,5	10	12	15	19	23	29	36	44	54	67	83
	3%	3%	0,2%	0,4%	0,5%	0,6%	0,8%	0,9%	1,2%	1,4%	1,8%	2,2%	2,7%	3,4%
Slovenia		6	6,6	7	8	10	12	15	19	23	28	34	41	50
		1%	1%	2%	2%	2%	3%	3%	4%	5%	6%	8%	9%	11%
Czech Republic		41	50,2	56	68	82	99	120	145	176	213	258	313	379
		2%	2%	2%	3%	4%	4%	5%	6%	8%	9%	11%	14%	17%
Hungary		2	3,5	4	5	6	7	9	11	14	17	21	26	32
		0,1%	0,2%	0,2%	0,2%	0,3%	0,3%	0,4%	0,5%	0,6%	0,8%	0,9%	1,2%	1,5%
Poland	63	35	45,4	51	63	77	95	117	145	178	220	272	335	413
	0,7%	0,4%	0,5%	0,6%	0,7%	0,9%	1,1%	1,4%	1,7%	2,1%	2,6%	3,2%	3,9%	4,8%
Slovakia		3	5,90	5,90	7	9	11	14	17	21	26	32	39	49
		0%	0%	0%	1%	1%	1%	1%	1%	2%	2%	3%	3%	4%
Greece	42	42	36	36	44	54	66	80	98	120	147	179	219	268
	3%	3%	3%	3%	3%	4%	5%	6%	7%	9%	11%	14%	17%	20%
Total	2960	3729	4273	4970	5720	6625	7719	9047	10661	12510	14733	17219	19944	23143
	3%	4%	5%	6%	7%	8%	9%	11%	13%	15%	17%	20%	23%	27%

Appendix K - Natural Gas Prices and Volumes

	Total Consumption 2004 (TJ)	Total Consumption 2004 (MToe)	Price on Natural Gas 2006 (€/TJ)177
EU-25	12 470 498	522140	8.6
EU-15	11 277 636	472195	8.76
Belgium	463 253	19396	7.11
Czech Republic	287 782	12049	7.34
Denmark	78 985	3307	6.97
Germany	2 805 000	117445	11.58
Estonia	9 673	405	2.84
Greece	21 465	899	
Spain	761 617	31889	7.24
France	1 506 150	63063	8.27
Ireland	61 631	2580	
Italy	1 890 577	79158	7.00
Latvia	22 885	958	4.05
Lithuania	22 407	938	4.45
Luxembourg	31 617	1324	9.01
Hungary	348 363	14586	7.88
Netherlands	983 869	41195	6.71
Austria	205 456	8602	10.82
Poland	344 862	14439	6.77
Portugal	59 533	2493	7.63
Slovenia	30 978	1297	7.96
Slovakia	125 912	5272	7.65
Finland	39 849	1668	7.79
Sweden	22 341	935	12.26
United Kingdom	2 346 293	98239	9.21
Bulgaria	36 822	1542	4.50
Croatia	54 412	2278	6.88
Romania	372 061	15578	4.59
Turkey	328 642	13760	
Norway	9 922	415	

Source: (European Commission and Eurostat, 2006)

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[177] Price on natural gas for Industry when VAT is excluded.