

Biogas systems in Finland and Sweden

Impact of government policies on the diffusion of anaerobic digestion
technology

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Hanna Savola

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Abstract

This research discusses the impact of government policies on the development of biogas systems in Finland and Sweden. Special focus is on the diffusion of anaerobic digestion technology as part of the renewable energy systems in both countries. Both Finland and Sweden have a relatively modest biogas production in the European context. While biogas production in Finland is mostly based on the collection of landfill gas, in Sweden however, the production of biogas using anaerobic digestion technology and its end-use application as vehicle fuel is rapidly increasing. The results of this research demonstrate that the more rapid diffusion of anaerobic digestion in Sweden than in Finland can be explained by differences in government policies.

The main driver for anaerobic digestion in Sweden has been the environmental policy, which is based on a set of environmental quality objectives the implementation of which is a shared responsibility of different government agencies. What has facilitated the implementation of biogas systems at regional level is the 'regional empowerment' approach on behalf of the government, which has motivated the municipalities to draft their own environmental and climate strategies. This approach has been beneficial to biogas due to the fact that the positive impacts of biogas systems are easier to understand from a regional perspective than from a national perspective. In practice, many of the projects designed by the municipalities to combat climate change at local level have focused on biogas systems development. The fact that Sweden has a more integrated strategic approach than Finland to combating environmental problems at regional level has been identified as one of the key factors influencing the more rapid diffusion of anaerobic digestion technology in Sweden.

Executive Summary

Finland and Sweden are two countries where a large share of domestic energy supply is based on renewable energy sources, 21% in Finland and 25% in Sweden respectively. This is a high figure in a European context. Having more diverse sources of renewable energy, however, is considered an important goal both for Finland and Sweden due to the fact that both countries are highly dependent on imported sources of fossil energy for their energy supply.

Reducing dependency on fossil fuels is important for three main reasons. The first reason is environmental. The burning of fossil fuels releases greenhouse gases to the atmosphere, these gases being the main cause of climate change. The second reason for diversifying the renewables portfolio is purely economic. As the cost of extraction of fossil fuels (and uranium) from reserves that are more difficult to access increases, so do the prices for these conventional energy sources. This trend is already visible in the current energy market prices. Continued implementation of the European emissions trading scheme, which was introduced in the year 2005, is expected to further increase the prices of fossil energy sources. The third argument for increasing domestic production of renewable energy is to secure energy supply in times of crisis.

Development of biogas systems is one way of diversifying a country's energy portfolio. Even though biogas only has a small total energy supply potential in both Finland and Sweden (less than 20 TWh), its positive economic, environmental and social impacts at regional level can be considerable. In general, distributed (regional) energy systems are considered to have several advantages over centralised systems: they allow individuals, organisations and communities to establish a secure, local energy supply. They generate local jobs and business. They promote the use of locally available resources and so-called wastes. In addition to these benefits, biogas systems can contribute to the achievement of multiple environmental objectives including reduced greenhouse gas emissions, a better soil fertility and decreased nutrient leaching to aquatic systems.

Production of biogas through anaerobic digestion (AD) is traditionally considered a waste treatment technology both in Finland and Sweden. While the political focus in Sweden has since the end of the 1990s shifted towards viewing AD as a method for producing renewable energy and combating climate change, in Finland AD is still largely considered a waste treatment method that competes with composting and possibly mass incineration in the near future. Sweden has, due to its strong focus on commercialisation of biogas in the transport sector, become known as the world leader in the use of biogas as vehicle fuel. In Finland, there is no clear preference for the end-application of biogas. In practice, this has led to a situation where a high proportion of biogas produced is simply flared off, one third in 2005, in the absence of an economically viable end-application alternative.

The purpose of this research was to (i) analyse what factors have contributed to a much earlier and more extensive development of biogas production in Sweden as compared to Finland and to (ii) understand what lessons Finland could learn from the Swedish biogas development in order to develop its own comprehensive strategy and design suitable policy approaches. It was discovered that there is not one *single* factor, which has contributed to biogas production developing faster in Sweden than in Finland. Rather, this development results from the combined effect of various government policies.

The general observation is that the Swedish approach to managing environmental issues is more comprehensive and integrative than the Finnish approach. This is demonstrated by the fact that rather than setting environmental objectives separately for each area of government policy, Sweden has since 1999 opted for a common set of environmental quality objectives,

the responsibility for the achievement of which is divided between different government agencies. One key policy area influenced by environmental motivations is fiscal policy. Sweden is currently in the process of carrying out a Green Tax Reform (increase environmental taxes, reduce income taxes), which was introduced in 2001. Environmentally motivated fiscal policy has in practice improved the private competitiveness of biogas, especially when used as vehicle fuel.

A more specific observation, which explains why biogas production has developed faster in Sweden than in Finland is that the Swedish government has since 1998 aimed to make municipalities the 'motor of ecological changeover' through the provision of investment subsidies to a number of municipally defined and run projects, which have environmental aims. Special attention has, since 2002, been given to projects that reduce emissions of greenhouse gases at local level, this being the highest priority environmental quality objective in Sweden. This 'regional empowerment' approach on behalf of the government has motivated the municipalities to draft their own environmental and climate strategies, which in turn has led to (i) shifting responsibility for the implementation of national environmental quality objectives to regions, (ii) increased understanding of the environmental situation regionally and (iii) better strategic approach on behalf of the municipalities with regard to achieving the Swedish environmental quality objectives. This approach has been beneficial to biogas due to the fact that the positive impacts of biogas systems are easier to understand from a regional perspective than from a national perspective. In practice, many of the projects designed by the municipalities to combat climate change at local level have focused on biogas systems development.

Finland could consider a similar approach to that of Sweden for the integration of environmental goals in different government policy areas both at national and regional level. This would require the definition of a set of environmental quality objectives at national level, and handing over the responsibility for their implementation to the appropriate parties – not forgetting proper monitoring and follow-up. Designing a suitable approach to encourage regional actors to take more responsibility for the local implementation of the national environmental strategy could also be considered.

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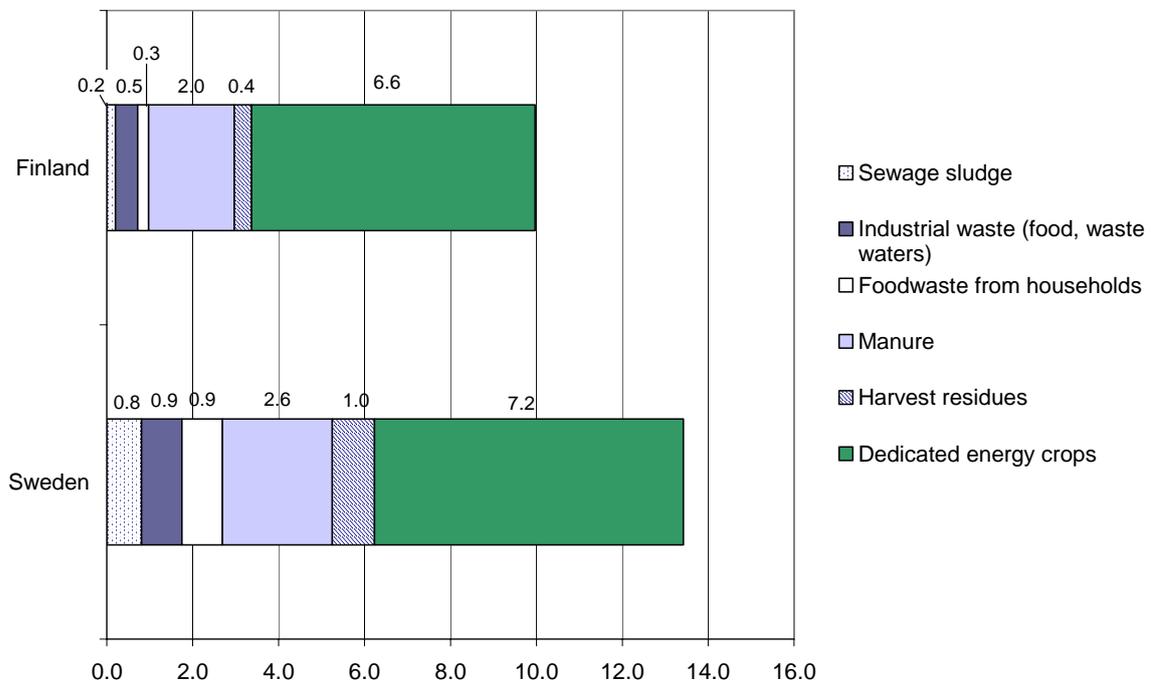
1 Introduction

This chapter will provide the reader with the necessary information to understand the composition of Finnish and Swedish energy supply systems, and the role of renewable energy, especially biogas, in these systems. Some of the key arguments for promoting the diversification of the renewables portfolio with biogas in both countries will be given. This will be followed by a description of the research purpose, including the key research questions that this thesis aims to answer. Afterwards, the main target audience who could make use of the research results will be defined and the research methodology used for carrying out the research will be laid out in more detail, including information on people interviewed and materials accessed, as well the analytical framework used for analysing the data collected. Finally, it will be clarified why this type of research is needed, followed by a presentation on the scope and limitations of this research.

1.1 Background

Production of biogas through anaerobic digestion (AD) has traditionally been considered a waste treatment technology both in Finland and Sweden. While the political focus in Sweden has since the end of the 1990s shifted towards viewing AD as a method for producing renewable energy and combating climate change, in Finland AD is still largely considered a waste treatment method that competes with incineration and composting. The annual biogas potential in Finland is estimated around 10 TWh, whereas the Swedish potential is slightly higher at around 13 TWh annually (see Figure 1).

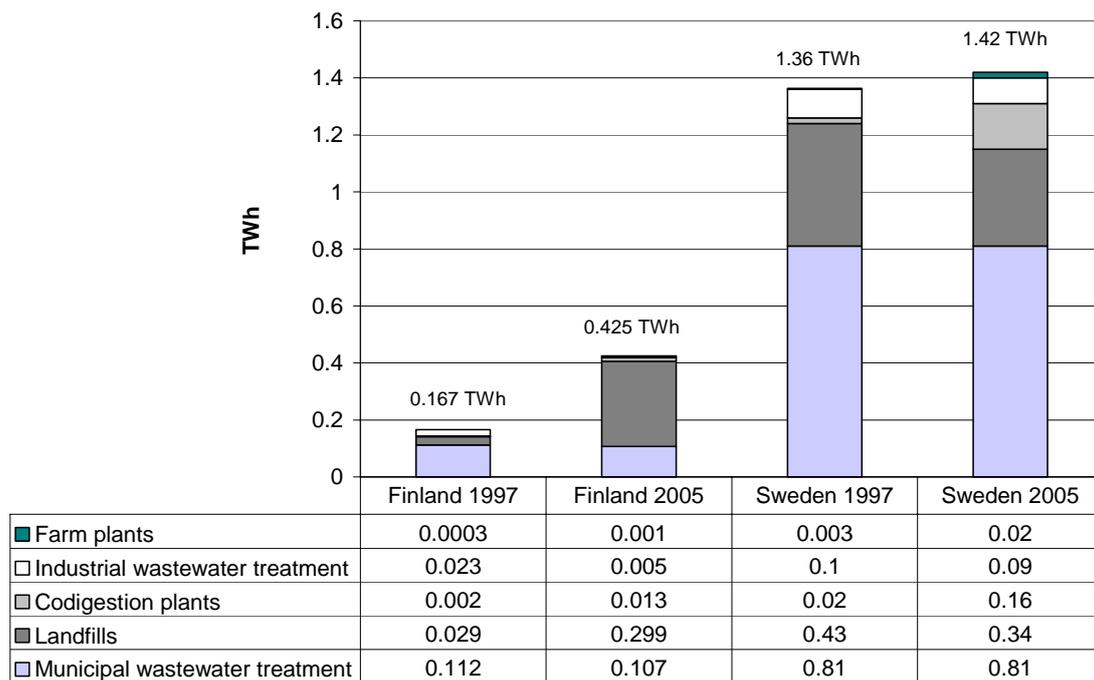
Figure 1: Estimated biogas potential in Finland and Sweden



Sources: Adjusted from Lampinen 2003, and Linne & Jönsson 2004. See Appendix 1 for more information on how the biogas potential for both countries was calculated.

When comparing the biogas potential in Finland and Sweden one must take into consideration several differences between the two countries. The first difference is that the population size of Finland is roughly 55% of the Swedish. This has an impact on the amount of waste available for digestion. The second difference is that Finland is 75% of the Swedish land area in size and that the highly agricultural southern part of Sweden, due to its more southern location, has a longer growing period than any parts of Finland. These geographic differences can influence the amount of specially grown energy crops available for AD, which is where the largest future potential for biogas production is found, as shown in Figure 1.

Figure 2: Biogas production in Finland and Sweden, 1997 and 2005



Sources: Leinonen & Kuittinen 2000, Kuittinen et al. 2006, Berglund 2006 p.8, Lindberg 1997, RVF 2006 p.14-15, 20

Note: Biogas from landfills is called landfill gas and collected from landfills, not produced using anaerobic digestion technology.

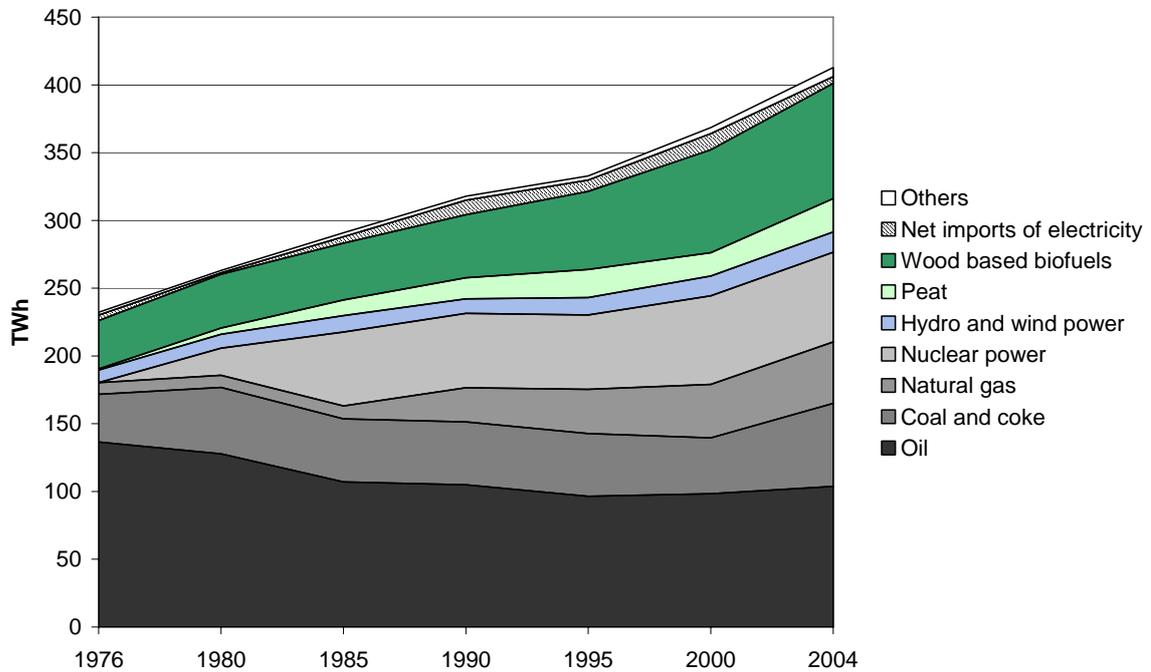
Figure 2 demonstrates that in 2005 the Swedish biogas production equalled 1.42 TWh corresponding to 11% of its estimated 13 TWh annual potential (Berglund 2006, RVF 2006). Despite the still relatively small total biogas production, Sweden has – due to its strong focus on commercialisation of biogas in the transport sector – become known as the world leader in the use of biogas as vehicle fuel. If Swedish biogas production had achieved its estimated 13 TWh potential in 2004, biogas could have covered 13% of the domestic fuel demand for cars, which was 99 TWh in 2004 (SEA 2005a).

Figure 2 shows that in Finland 0.4 TWh of biogas was produced in 2005 (Kuittinen et al. 2006). This is 4% of the estimated 10 TWh annual potential. It should be pointed out that the collection of landfill gas makes up 70% of the Finnish biogas production. Collection of landfill gas is an end-of-pipe technology for dealing with the methane emissions from landfills and should not be confused with anaerobic digestion, which is considered a preventive technology. Preventive technologies are preferred over end-of pipe solutions due to the fact that they prevent environmental problems from occurring in the first place. The three main advantages

of AD as a preventive technology are that it (i) maintains sustainable natural cycles through the recycling of nutrients while preserving soil organic matter, and (ii) contributes to curbing climate change through provision of renewable energy which can be used to replace fossil fuels.

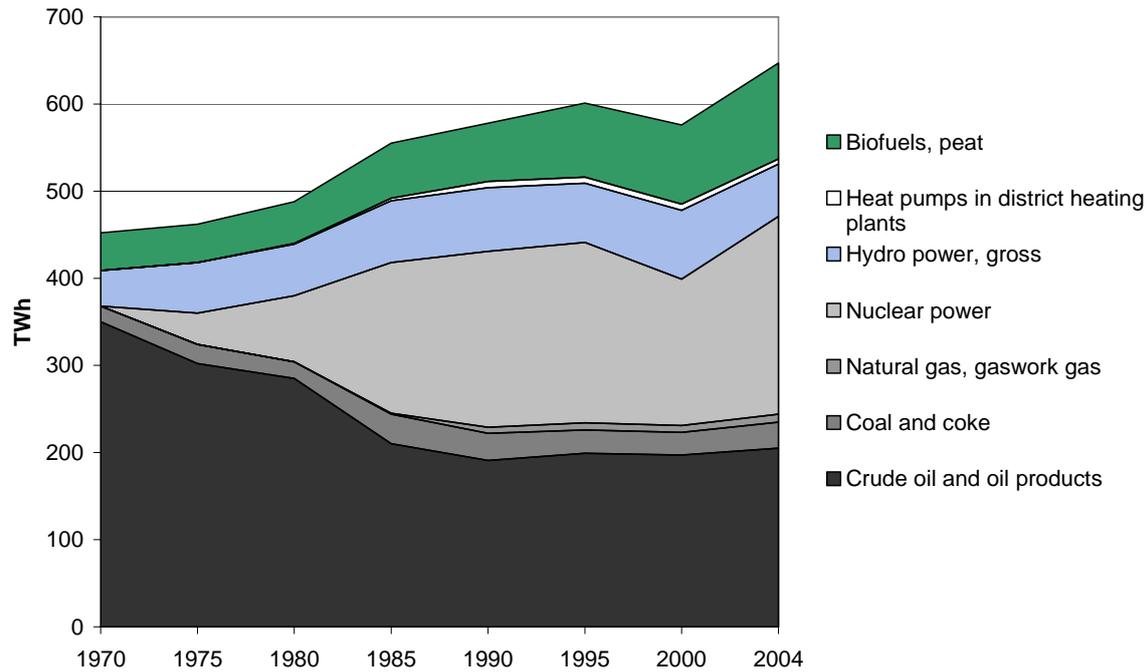
If we compare the Finnish and Swedish biogas potential to the total energy supply in the country, it is relatively insignificant. As can be seen from Figure 3, the total energy supply in Finland was 413 TWh in 2004. One can also see that biofuels made up 85 TWh of this supply (110 TWh including peat), hydro and wind power contributing with a 15 TWh share. As demonstrated in Figure 4, Sweden had a total energy supply of 647 TWh in 2004, of which 110 TWh came from biofuels (figure includes peat) and 60 TWh from hydro power in 2004. Despite the relatively high proportion of renewable energy, both Finland and Sweden are heavily dependent on imported fossil fuels as well as nuclear power in their energy supply.

Figure 3: Total energy supply by energy carriers in Finland, 1976-2004, TWh



Source: Statistics Finland 2006a

Figure 4: Total energy supply by energy carriers in Sweden, 1970-2004, TWh



Source: SEA 2005b, p.8-9

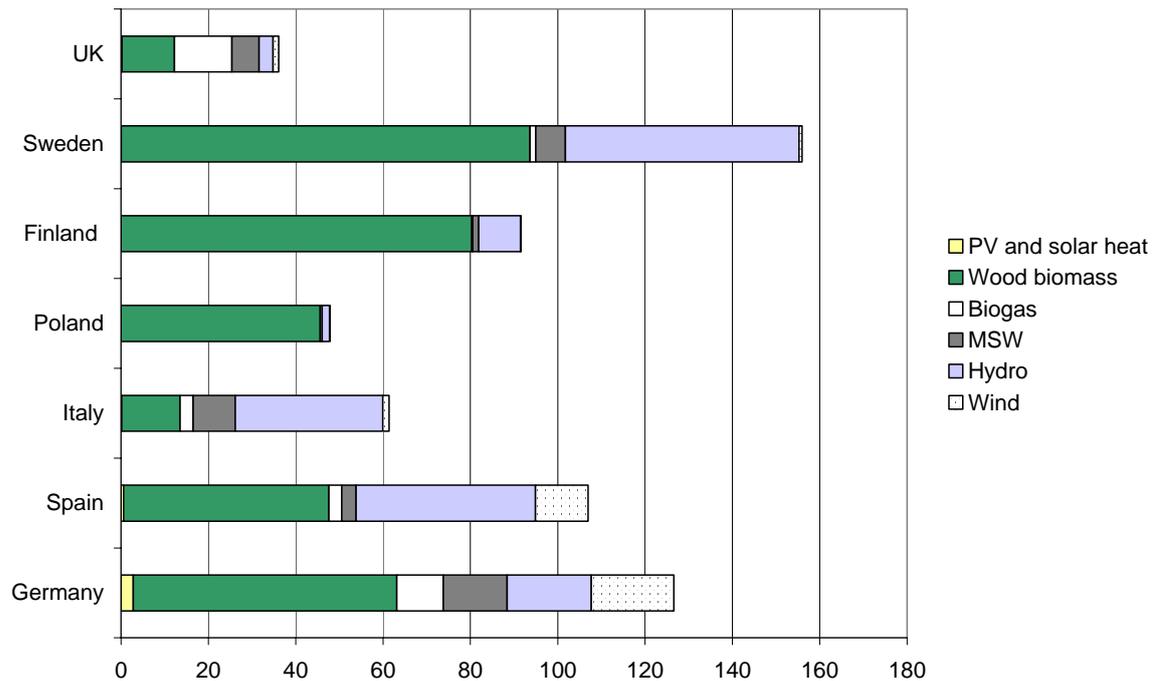
Sweden has set itself a goal to significantly reduce the country's dependence on fossil fuels by 2020 through, among other things, the promotion of renewable energy (Commission on Oil Independence 2006, p.5). The Finnish Minister of Finance, Mr Eero Heinäluoma has since August 2006 promoted a similar strategy for Finland (Heinäluoma 2006). The key arguments for reducing dependence on fossil fuels and increasing the production of domestic renewable energy are as follows (i) secure energy supply in times of crisis (ii) reduce greenhouse gas emissions from the burning of fossil fuels (iii) ensure access to affordable sources of energy as prices of fossil fuels and uranium go up.

Because there is no single large source of renewable energy that could replace all conventional fuels, the prices of which are expected to continue rising not only due to the increasing extraction costs but also due to the introduction of a European (greenhouse gas) emissions trading scheme in 2005 (based on the Kyoto protocol), the future energy portfolio will have to be more diversified than the one today. In this context, anaerobic digestion, with its 10 TWh potential in Finland and 13 TWh potential in Sweden, can be considered a technology which has a role to play in each country's future energy portfolio.

Production of renewable energy is favourable to the introduction of distributed energy systems. This term refers to energy systems, which are based on local production and distribution of energy as opposed to the current system of large, centralised power plants. Biogas production is a prime example of a distributed energy system because it is based on anaerobic digestion of locally available biomass, including urban waste products, agricultural waste and specially grown energy crops. Local actors consider biogas systems to have many advantages at regional level, including: security of fuel supply when fuel is produced locally; reduced greenhouse gas emissions leading to reduced climate impact; reduced emissions to air; treating biodegradable waste in an environmentally friendly manner; creating new jobs; and biogas giving the city a positive image (Erfors 2006).

While this research only considers biogas production in Finland and Sweden, the reader should be aware of how these countries compare with their European counterparts in their supply of renewable energy. In 2003, renewable energy covered an exceptionally large share of total energy supply in Sweden (25%) and Finland (21%) (Eurostat 2006c). A large part of the renewables portfolio in both countries is based on forest biomass, and on hydro power in Sweden. Sweden has a somewhat more diversified renewables portfolio than Finland (see Figure 5), while Germany seems to be the current European leader in the development of a balanced supply of renewable energy from different sources.

Figure 5: Production of renewable energy in selected EU countries, 2003



Source: Eurostat 2006c (Note: peat not considered renewable energy in the EU and hence not included in the figures).

1.2 Purpose and research questions

This research aims to analyse what factors have influenced the development of biogas markets in Sweden and Finland since the introduction of anaerobic digestion technology in the 1960s. The key focus of this research is to evaluate to what extent the political system has acted as a driver or barrier to the development of biogas markets in each jurisdiction since both countries became members of the EU in 1995 (i.e. the past 10 years). The influence of the socio-cultural and techno-economic systems to the development of biogas production is also considered. Finally, this research aims to evaluate the existing strategies for the production and end-use of biogas in both countries in order to reflect upon what kind of a biogas strategy the Finnish government should consider in the future.

In line with the above described aims of the research two research questions were formulated:

Research Question 1: What factors have contributed to a much earlier and more extensive development of biogas production in Sweden as compared to Finland?

Research Questions 2: What lessons could Finland learn from the Swedish biogas development in order to develop its own comprehensive strategy and design suitable policy approaches?

1.3 Audience

Biogas systems can be very varied and complex to understand. What adds to this confusion is the fact that anaerobic digestion can be considered both a technology for treating waste and producing renewable energy. Because anaerobic digestion is still a relatively new technology in the solid waste management and energy supply sectors, information on the purpose that biogas systems can serve (including environmental aspects of biogas production) and the role that government policies can play in biogas systems diffusions is still somewhat scarce. An interested party often needs to look for information from many different sources, which is a time consuming process. This research aims to overcome this problem by providing politicians, citizen groups and the various actors in the biogas chain with a comprehensive overview on the purpose that biogas systems can serve in the wider context of waste and energy systems, and the role that government plays in biogas systems development.

Politicians can use the information provided in this research to better understand how environmental considerations can drive technological development and how government policies can be shaped to reinforce development of new, and potentially superior, environmental technologies. Information provided in this research is especially aimed at the Finnish politicians, who can use it to understand the possible strengths and shortcomings of the current government policies with regard to biogas systems development, and to shape these policies as appropriate.

1.4 Research methodology

This thesis is a country study. It compares the development of biogas systems in Finland and Sweden, identifying those (i) socio-cultural, (ii) political and (iii) techno-economic factors, which have driven or hindered the development of biogas systems in each jurisdiction. These factors are considered to be the drivers and barriers, which according to Sartorius and Zundel (2005) to a large degree define the success or failure of an environmental innovation in a chosen society (in this case Finland and Sweden). The identified drivers and barriers will be compared on a country to country basis in order to identify which have been the key differentiating factors between the two countries. These differentiating factors will then be used to explain why the development of biogas systems has been faster in Sweden than in Finland. Finally, recommendations will be made concerning the strategy that Finnish government should consider for future biogas systems development in the country. These recommendations will be based on the specific characteristics of the Finnish biogas system, and lessons learnt from the Swedish case. Both quantitative and qualitative data have been collected as observations of the socio-cultural, political and techno-economic factors influencing the development of biogas systems in the two countries.

The main data gathering methods were:

1. Interviews: The purpose of the semi-structured interviews had been explained to interviewees beforehand. Interview questions followed specific themes but the

questions varied depending on the interviewee's background. Two thirds of the interviews were personal (i.e. face to face), one third of the interviews being conducted over the phone. Interviewees in the two countries represented the following interest groups and organisation:

- Academia
- Government
- Municipalities
- Waste management companies
- Farmers
- Producers of biogas (AD technology)
- Gas distribution and energy companies
- Car industry
- Consultancy and other specialist services

Swedish and Finnish interviewees' names, name of the organisation they work for, date and type of interview and the interest group, the opinions of which each interviewee is expected to represent, are available in Appendix 2. Twenty written interview results that have been confirmed by the interviewees are available in electronic format. The Finnish part of data collection was facilitated by a two-week research exchange in the Technical Research Centre of Finland during August 2006. This research exchange was organized through the Bioenergy Network of Excellence, which receives EU funding for its activities.

2. Document review: Documents published by the above-described key actors concerning different aspects influencing biogas systems composition and development, as well as environmental performance of biogas systems in comparison to competing alternatives, were reviewed. These information sources included: legal documents (EC Directives, national laws), strategic government policy documents, technical studies (e.g. life cycle analyses), and studies and reports (e.g. on biogas and other renewables market development).

To summarise, two key methods of data gathering, document reviews and interviews with a large number of informants presenting the interests of different actors in the biogas chain, were used to collect data for the two national contexts.

In addition to these two key data gathering methods, participation in the World Bioenergy Conference organised by SVEBIO (Swedish Bioenergy Asssocation), which took place in Jönköping between May 30 and June 1 2006, served the purpose of gaining an overall view of the developments in the world bioenergy markets, the role of biogas in renewable energy systems and potential new technologies for production of renewable methane gas. In addition, participation in specific workshops during the conference provided insight into specific aspects of biogas systems development. The following two workshops proved to be especially valuable: 'Sweden as a global case for systems development of biofuels' workshop, and the 'Agroptigas workshop' that presented a biogas case study.

An analytical framework developed by Sartorius & Zundel (2005) in “Time strategies, Innovation and Environmental Policy” was used to compare the two country case studies and present and analyse the data in a structured manner.

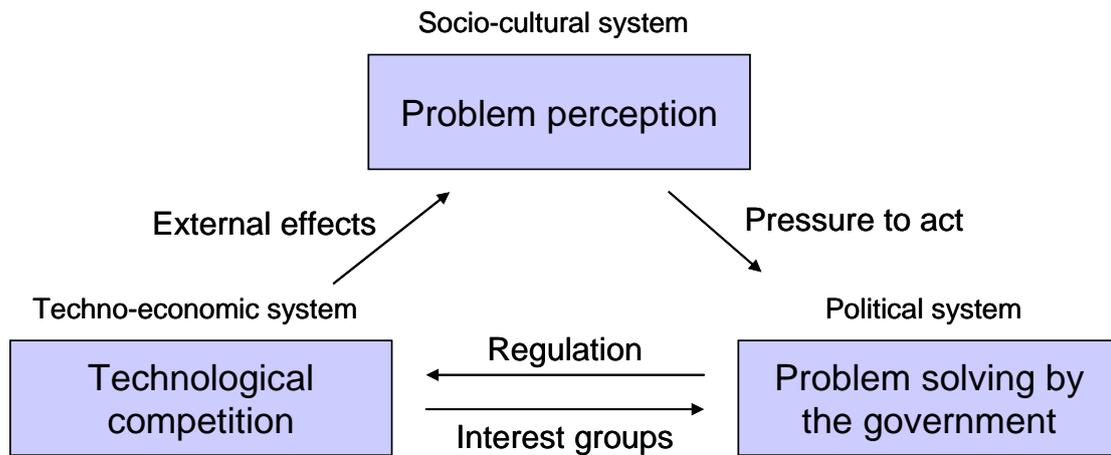
Information on factors influencing the development of biogas systems in other countries, mainly Germany and Denmark, was also collected during document review and interviews. This was important for understanding how biogas systems can develop in other national contexts than the Finnish and Swedish. Separate case studies for these countries have not been presented in this research but one should bear in mind that both Germany and Denmark have chosen a different route than Sweden in end-application of biogas. In Sweden use of upgraded biogas as vehicle fuel is promoted by the government whereas German and Danish governments are more inclined to support use of biogas for combined heat and power production. In Finland there is no clear preference for one or the other yet.

1.5 Theoretical background and analytical framework

An analytical model presented by Sartorius in “Time strategies, Innovation and Environmental Policy” (Sartorius & Zundel 2005) was used to analyse the development of anaerobic digestion technology in a historical context in Sweden and Finland. According to Sartorius & Zundel, the implementation of an environmental innovation is influenced by the interplay of three societal subsystems: socio-cultural, political and techno-economic. The key idea behind their model is that an understanding of an environmental problem in the socio-cultural sub-system (scientists discover an environmental problem, the media writes about it and the general public becomes concerned) often puts pressure on the political system. If this pressure is large enough, politicians take action to limit the negative external effects of a specific technology and promote environmental innovation. Political action (regulation and economic incentives together) then influences the techno-economic sub-system where the implementation of an environmental innovation takes place.

According to Sartorius & Zundel (2005), political system plays a more important role than the socio-cultural and techno-economic systems in the implementation of a sustainable innovation. They also emphasise that the interaction between the three societal sub-systems is a continuous and dynamic process since new technologies always lead to the appearance of new environmental problems, which require new types of solutions. To give an example: in Sweden, incineration of waste was during the 1970s and 1980s considered an environmental innovation, which would reduce environmental problems related to landfill of waste while replacing fossil fuels. However, the implementation of incineration technology led to the discovery of new environmental problems in the 1980s. Back then the main problem was considered to be the significant air emissions of especially dioxins from incineration facilities (more recently issues such as lack of nutrient recycling and end-disposal of the toxic ash have also been on the agenda). This “dioxin scare” led to an attempt to improve incineration technology itself (better flue gas cleaning equipment) but also to develop other technologies, such as coprototyping and anaerobic digestion, which would altogether avoid the problem of unhealthy air emissions in the first place. This brings us back to the beginning of the technological development cycle. Figure 6 below demonstrates how the three societal subsystems continuously and dynamically interact in dealing with environmental problems.

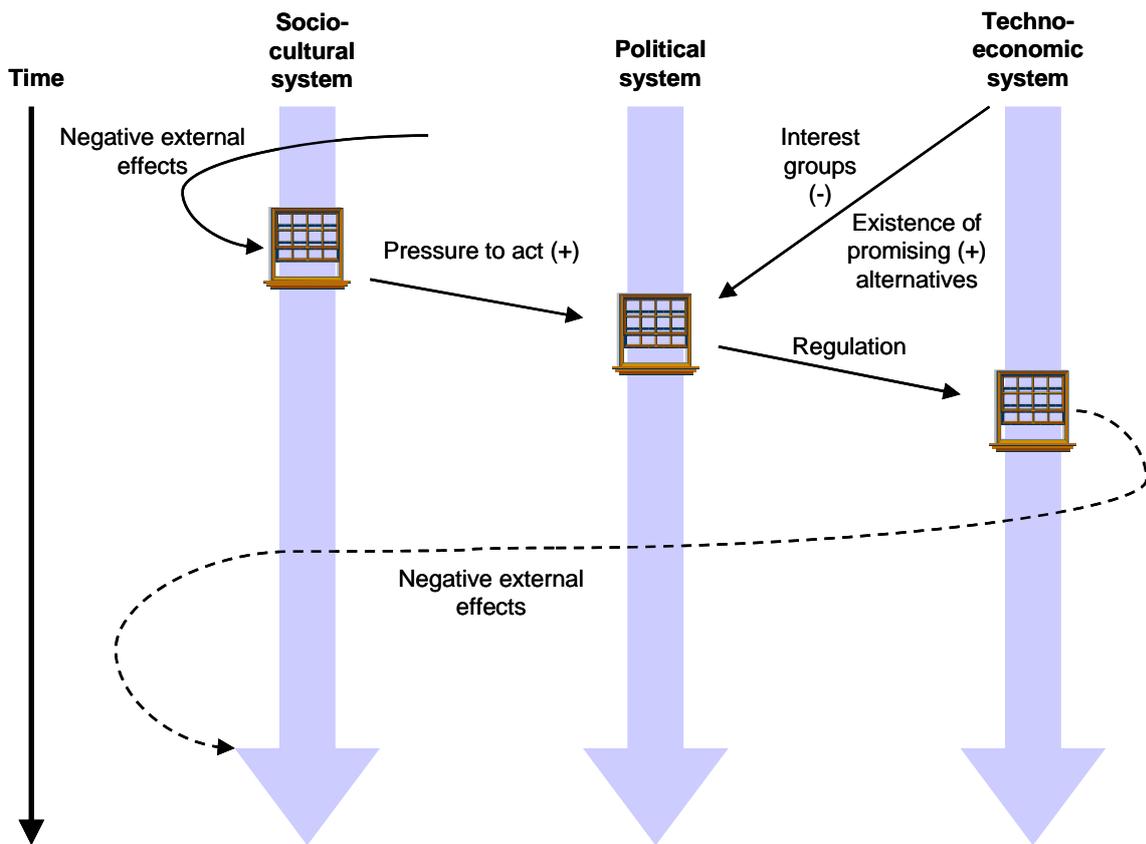
Figure 6: Interactions of societal subsystems in dealing with environmental problems



Source: Sartorius & Zundel 2005, p. 48

It is very important that the government is aware of the dynamic character of the environmental innovation process, because it allows the government to react to the changes in the socio-cultural and techno-economic subsystems in a timely manner, when the so-called windows of opportunity for economically sustainable innovations open (Sartorius & Zundel 2005). A window of opportunity presents a specific point in time when the possibilities for environmental innovation to succeed are higher than otherwise due to changes in one of the three societal sub-systems (see Figure 7).

Figure 7: A typical sequence of windows of opportunity in the societal subsystems



Source: Reproduced from Sartorius & Zundel 2005, p.49

Identification of windows of opportunities is a key concept of the Sartorius model and can be easily explained through a case study on the phase-out of CFCs presented in Sartorius & Zundel (2005) “Time strategies, innovation and environmental policy”. A window of opportunity for the phase-out of CFCs opened in the socio-cultural system in 1974 when the Molina-Rowland hypothesis on how CFCs destroy ozone was published in *Nature* (Molina & Rowland 1974). These scientific findings were backed by consumer protests (another window of opportunity in the socio-cultural system), which to some extent counterbalanced the objections of the chemicals industry (the techno-economic subsystem) to reducing the production of CFCs - a business of significant economic relevance at the time. According to Sartorius & Zundel (2005), the readiness of the political system to regulate CFCs constituted the main window of opportunity for the development of new, environmentally friendlier technologies. The political readiness was based on the growing scientific evidence in the socio-cultural sub-system on the potentially catastrophic results of continued ozone depletion on human health alone, for example.

In this piece of research anaerobic digestion was considered an environmental innovation, the implementation of which depends on the interaction of the political subsystem with the socio-cultural and techno-economic subsystems. Comparison of AD with competing waste and energy technologies from an environmental perspective was carried out to justify why AD can be considered an economically sustainable innovation in the waste management sector. In line with Sartorius’ model, the key windows of opportunity for the implementation of anaerobic digestion technology were identified in the social, political and techno-economic systems at different points in time. It was then further analysed if these windows of opportunity were

utilised to the benefit of AD technology. Finally, Sartorius' claim that the political system plays a more important role than socio-cultural and techno-economic systems in the implementation of a sustainable innovation was tested through an evaluation of the two country case studies from an environmental innovation policy perspective. This analysis was expected to reveal important differences in the socio-cultural, political and techno-economic sub-systems, which could then be used to explain why biogas production in Sweden is growing faster than in Finland.

As a new technology AD can suffer from the so-called *path dependence* or *lock-in effect* as is often the case for new technologies that need to compete against an established counterpart (Sartorius & Zundel 2005, p.13). Lock-in refers to short-term, and path dependence to long-term dominance of a potentially inferior technology, which is based on the other technology having penetrated the market before the launch of the new, potentially superior technology. This gives the potentially inferior technology financial and informational advantages over the new technology. For instance, high initial set-up costs can act as a barrier to investing in new technology serving a similar purpose. In addition, technological improvements from learning-by-doing and increased information sharing over the benefits of a specific technology can further solidify its market position (larger number of companies implement this technology as it gains wider acceptance, which is followed by construction of supporting infrastructure and forming of commercial relations with other actors in the market).

Chapter 3 will present the two country case studies and provide an analysis of each using the framework presented by Sarorius and Zundel (2005) in "Time strategies, Innovation and Environmental Policy".

1.6 Research justification

Finland was chosen as the main focus of this research because, considering the country's otherwise excellent bioenergy record, development of biogas systems based on AD as opposed to landfill gas collection in the country has been slow. The demand for this research is based on the fact that no earlier studies have evaluated the combined impact of different government policies on overall biogas systems development in these two countries. Finland is at the cross-roads: it is now time to decide whether the government should support the development of biogas systems with its policies, and if so, what the future biogas strategy should look like, and how government policies could support the implementation of this strategy. Sweden was chosen as a comparative case study because of the geographic, climatic, socio-economic and political similarities between the two countries.

The interviewees mentioned in the previous chapter were chosen for the following reasons: government officials play a key role in influencing the biogas systems development in the desired direction, whereas actions taken by different actors in the market (e.g. waste management and energy companies, farmers) are an important way of determining the absence, success or failure of specific government policies. Consultants and providers of specialist services (e.g. designers of biogas plants and providers of biogas technology) are often well informed on the market situation as well as the influence of government policies on biogas systems. Biogas producers (e.g. farmers) act as suppliers of biogas, which is often distributed for specific end-uses by energy companies. Energy companies own the infrastructure for production and delivery of specific energy services.

Semi-structured interviews were chosen as the main means of information gathering for this research. This was due to the fact that biogas systems are complex, with a large number of potential participants in still relatively undeveloped markets. In order to gain a proper

overview of the current situation with regard to the impact of government policies and specific concerns of different actors it was absolutely necessary to establish a personal contact with different interested parties, based on a discussion outline rather than a ready-made questionnaire.

The initial document review served the purpose of gaining background information on the development of biogas systems in both countries, the main policies affecting biogas systems development, as well as key environmental and economic considerations of biogas production. The final document review served the purpose of cross-checking some of the results from interviews and as a way of expanding on new information, especially on government policies, that emerged from the interviews.

The framework of Sartorius & Zundel (2005) was chosen because it is directly applicable to analysing the government's role in the market diffusion of a specific environmental technology, in this case anaerobic digestion. This technology focus is one of the greatest advantages of the chosen framework over others considered, which were more market-oriented. In addition, this framework has the benefit of conveying a difficult message in a simple manner, through the use of good visual aids. Both country cases are presented using this model developed by Sartorius & Zundel (2005), it being an excellent tool for demonstrating how interactions between the socio-cultural, political and techno-economic societal subsystems can drive or hinder the implementation of a specific environmental technology. This framework is especially useful for country comparisons, as demonstrated in Sartorius & Zundel (2005) “Time strategies, Innovation and Environmental Policy”.

1.7 Scope and limitations

The geographical focus of this research is two Nordic countries: Finland and Sweden. Inclusion of more countries in the comparison would have allowed for a wider understanding of biogas production in a European context, but taking into consideration the time constraints for this research, it would have made the review on the impacts of government policies on biogas systems development more limited.

This research focuses on the development of biogas systems, which are based on the production of renewable methane gas (i.e. biogas) through anaerobic digestion of urban and agricultural waste, or specially grown energy crops. Because anaerobic digestion is considered to be both a waste treatment and energy production technology, other competing technologies in both sectors were also evaluated. Of specific interest in this evaluation was how the environmental impacts of biogas systems compare with competing technologies. Economic aspects of biogas systems in comparison to other waste and energy systems have also been discussed in conjunction with the country case studies due to their significant influence on the willingness of market players to engage in biogas production and distribution.

Based on a framework presented by Sartorius & Zundel in “Time strategies, Innovation and Environmental Policy” (Sartorius & Zundel 2005) societal influences on the development of biogas systems were considered from the point of view of three societal subsystems: socio-cultural (scientific evidence and citizen concern for specific environmental issues), political, and techno-economic (actors hoping to benefit from the development of the biogas market). This division serves well the purpose of this research, which aims to show how the interaction of different societal interest groups has shaped government policies towards anaerobic digestion and other waste, or renewable energy technologies. The timeframe for this analysis is from the 1960s to the present, as it was during the 1960s when the diffusion of anaerobic

digestion echnology started in the waste water treatment plants in both countries, with one earlier exception in Finland (Helsinki 1932).

In order to provide a more comprehensive view on the influence of government policies in the development of biogas systems, various government policies were reviewed in some detail. Waste and energy policies were first reviewed, but based on own desktop research and the remarks made by various interviewees, it soon became evident that governments' environmental, fiscal, agricultural and transport policies also needed to be reviewed. The timeframe for the analysis of government policies was from 1995 to date. This timeframe was chosen for two reasons. The first reason is that in 1995 both Finland and Sweden became members of the European Union, making EU policies applicable to both countries. The second reason is that a ten year period is expected to provide sufficient information on the consistency of government policies with regard to biogas systems development.

Due to a relatively high number of personal interviews, the opinions of different interest groups are well represented in this research. Good coverage of the different interest groups through interviews has allowed for a sufficient cross-comparison of data referred to in different documents and provided by individuals. One should, however, still be aware that different interest groups have very different opinions on, for instance, the desired end-application of biogas and to what extent government policies should be used to promote specific biogas systems. All of these arguments may be justified under specific circumstances, adding to the confusion of the policy maker. One of the key dilemmas in Finland, for example, is whether to use biogas for CHP or transport purposes. Comprehensive analysis on the various opinions concerning biogas systems development allows this research to provide some conclusions and recommendations on issues such as what end-application biogas should have, especially in Finland where the future 'biogas strategy' is still open for discussion.

2 Biogas systems and anaerobic digestion

Biogas is a methane rich gas, which is formed when specialised micro-organisms decompose organic matter in anaerobic conditions (in the absence of oxygen). In a natural environment this phenomenon occurs spontaneously in swamps and in the stomach of cows, for example. In a man-made environment, biogas forms spontaneously in landfills, and is produced in specially built anaerobic digestion facilities. Biogas is considered a renewable fuel because the raw-materials used for making biogas that are of fresh plant and animal origin, are constantly regenerated (plants capture carbon dioxide through photosynthesis as they grow). This means that when biogas replaces fossil fuels, greenhouse gas emissions can be reduced.

Environmental benefits of anaerobic digestion technology include:

1. Reduced greenhouse gas emissions due to: (i) improved waste treatment (ii) replacement of fossil fuels with a renewable fuel (iii) avoided emissions from the production of chemical fertilisers (iv) possibility for recycled soil to act as carbon sink.
2. Improved recycling of plant nutrients.
3. Preservation of soil organic matter in digestate.
4. Increased biodiversity due to flexibility in using various crops as raw material.

Chapter 2.1 will give a short-overview of the production and use of biogas. Chapter 2.2 addresses some of the challenging issues that arise from the variety of raw materials, the number of actors involved in the biogas chain, the many potential end-use applications of biogas and the multiple environmental purposes biogas systems can serve. Chapter 2.3 provides an overview of the technologies that compete with anaerobic digestion in the waste and energy sectors, comparing their environmental impacts with those of AD (systems lifecycle perspective).

2.1 Biogas production and consumption

This overview on the production and use of biogas is split into four sub-sections, which describe the following: what raw-materials are suited for anaerobic digestion, the anaerobic digestion process itself and the end-applications of biogas in the energy markets. This section serves the purpose of providing all readers the basic information needed for understanding the biogas systems, which according to Berglund (2006 p.1) “are multifaceted and complex, due to a number of factors such as: (i) the large variation in raw materials, digestion technologies and end-use applications of biogas, as well as the digestate produced, (ii) the large variety of objectives and issues to be addressed in the implementation of biogas systems, and (iii) the many actors involved.”

2.1.1 Raw materials

Raw materials that are used for the production of biogas can be divided into three groups: urban waste products, agricultural by-products and dedicated energy crops (Berglund 2006). Table 1 describes in more detail the types of raw materials that belong to each of these groups. As a general rule, it can be said that plant materials containing cellulose can be degraded by methane producing bacteria whereas woody materials, which contain lignin, are hard to digestate by the bacteria. Even though suitable for anaerobic digestion, paper and cardboard materials are usually not subject to this treatment on a large scale due to their suitability for other uses such as material recycling or thermal recovery. Those interested in the economic

and environmental aspects of raw material recovery and their anaerobic treatment are referred to Appendix 3 for more information.

Table 1: Categories and types of raw materials used in the anaerobic digestion process

Categories of raw materials	Types of raw materials
Urban waste	Waste water ¹ Industrial waste ² Household waste Restaurant and catering waste Park and garden waste
Agricultural by-products	Manure Harvest residues ³
Dedicated energy crops	e.g. Grasses, grain, maize, sugar beet

1) municipal sewage sludge and industrial waste water

2) e.g. slaughter houses, starch factories, breweries, distilleries, sugar production, dairy industry, cooking oil production, paper & pulp industry

3) e.g. waste potatoes (not suitable for sales), tops and leaves of sugarbeet, chaff of grain

Source: Berglund 2006, Nordberg 1999, Linné and Jönsson 2005

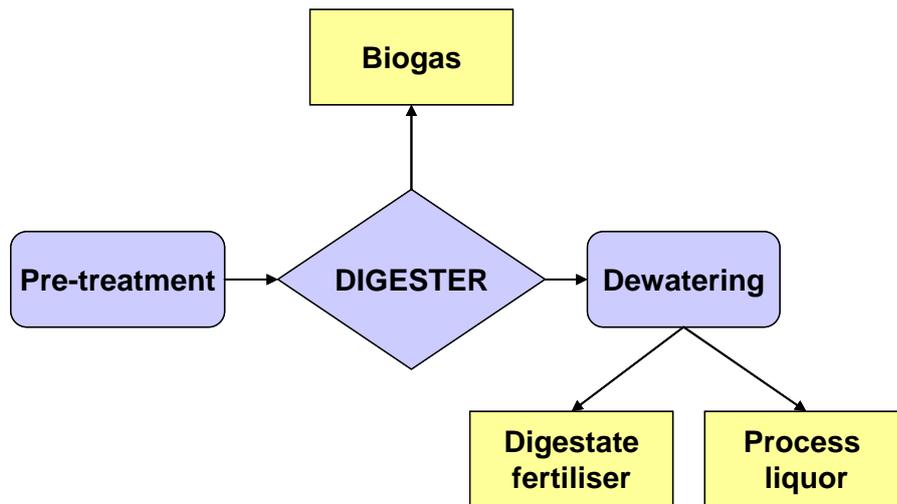
2.1.2 Anaerobic digestion

Various types of biodegradable waste and, more recently, energy crops, are usually co-digested in the anaerobic digestion process in order to maximise the biogas yield. Pre-treatment of raw materials is sometimes needed depending on the characteristics of the material treated. The key aim of pre-treatment is to hygienise¹ and homogenise² the incoming waste. After pre-treatment, the raw materials can be fed into anaerobic digestion tanks where biogas formation takes place. The digested residues are then treated (usually dewatered), which produces two by-products: digestate fertiliser and process liquor. Proper storage of the digested residues is very important as 10-15% of biogas production takes place at this stage of the process (Berglund 2006). A simplified process overview of an anaerobic digestion plant has been provided in Figure 8. For more information on technical aspects of biogas production please refer to Appendix 4.

¹ remove undesired substances such as metals and kill pathogens

² make incoming waste fractions into equal size particles to make their digestion easier

Figure 8: Simplified process overview of an AD plant



The main end-product from the anaerobic digestion process is biogas, which contains typically 60-70% methane (CH₄) and 30-40% carbon dioxide (CO₂), but also water vapour and traces of, for example, nitrogen (N₂), hydrogen sulphide (H₂S) and ammonia (NH₃) (Berglund 2006). Digestate fertiliser is a by-product of anaerobic digestion. It can be used as organic fertiliser in agriculture, with an added advantage of simultaneously acting as a soil improver, as it increases the soil organic matter content thereby improving the capability of the soil to retain nutrients. In addition to digestate, a watery liquid called process liquor arises as a by-product of the AD process. Some of the process liquor can be fed back to the process and the rest can either be used as liquid fertiliser in agriculture or must be treated as waste water.

Even though biogas is considered the main product of AD, the possibility to apply digestate to agricultural land is of primordial importance if the full environmental benefits of biogas production are to be achieved. When digestate is returned to arable land the full biogas eco-cycle has been completed. Production of good quality digestate demands that the incoming streams of raw materials are clean. If the incoming waste streams are contaminated, the quality of digestate suffers and its application to arable land might be prevented. This explains why source separation and separate collection of biodegradable waste is so important (link from process back to inputs).

2.1.3 End-use applications

The least desirable use for biogas is to *flare it off* to avoid greenhouse gas emissions when no suitable end-application for the biogas produced can be identified. Technically, the simplest energy application of biogas is for *heat production*. Natural gas boilers can be run on raw biogas, from which water has been removed, with only minor technical adjustments to the boiler. Between 10% (large scale plants) and 30% (farm scale plants) of the heat produced is usually consumed inside the plant, for the running of the digester (Berglund & Börjesson 2003). The rest of the heat can be used for heating buildings close to the plant or for district heating purposes. Economic gains in this case usually result from using locally produced biogas instead of bought-in oil for combustion. In smaller production systems some of the biogas might need to be flared off (i.e. burned to avoid greenhouse gas emissions) at times when heat demand is low such as the summer months. In larger systems, on the contrary, biogas can be used as part of the baseload for the district heating system throughout the year. (SBGF 2004). Partially cleaned biogas can also be inserted into *town gas pipeline networks* for residential use as cooking gas, for example.

Biogas can also be used for *combined heat and power (CHP) production*, the technology for which is well-developed. In this case, the energy content in biogas is used more effectively than in heat production alone. The overall conversion efficiency ranges between 30-40% electricity and 50% heat, depending on the plant size and conversion technology (Börjesson & Berglund 2006). When used for CHP production, pre-treatment of the biogas for the removal of water vapour, particles and corrosive components such as H₂S and chlorinated hydrocarbons is necessary (SBGF 2004). In Germany and Denmark, use of biogas for CHP production is very common.

The most advanced use of biogas is its insertion into the *natural gas network* or use as a *car fuel*. In both cases, biogas must undergo the same pre-treatment as when used for CHP production. This pre-treatment is carried out to remove constituents that are either harmful to human health or cause corrosion in the car engine and natural gas pipeline. In addition to this pre-treatment, the energy value of biogas must be increased to the same level as that of natural gas through the removal of carbon dioxide from biogas in a gas upgrading facility. Biogas is then compressed and either inserted to the natural gas grid or stored before use in the car engine. It should be mentioned that the upgrading of biogas to natural gas quality is considered an expensive process. In addition, the use of biogas as vehicle fuel requires special refuelling stations, which are a costly investment, and the main reason for the ten times higher costs of distribution infrastructure for biogas as opposed to ethanol (Andersson 2006, Erfors 2006). For information on different biofuels and types of vehicles running on them, please refer to Appendix 5.

Production and distribution costs for biogas increase with every step in the process (from flaring off to use in the car engine). However, each of these steps can also add value to the final product, which can then be sold at a higher price (see Table 2). This statement is based on the assumption that the biogas end-product is cost competitive in comparison to other products in the market, since customers are rarely willing to pay more for an environmentally friendly alternative. The end-use of biogas is often determined through government policies having an impact on the price of end-product, including energy taxation and subsidies or quotas on the production of renewable energy among others.

Table 2: End-uses of biogas

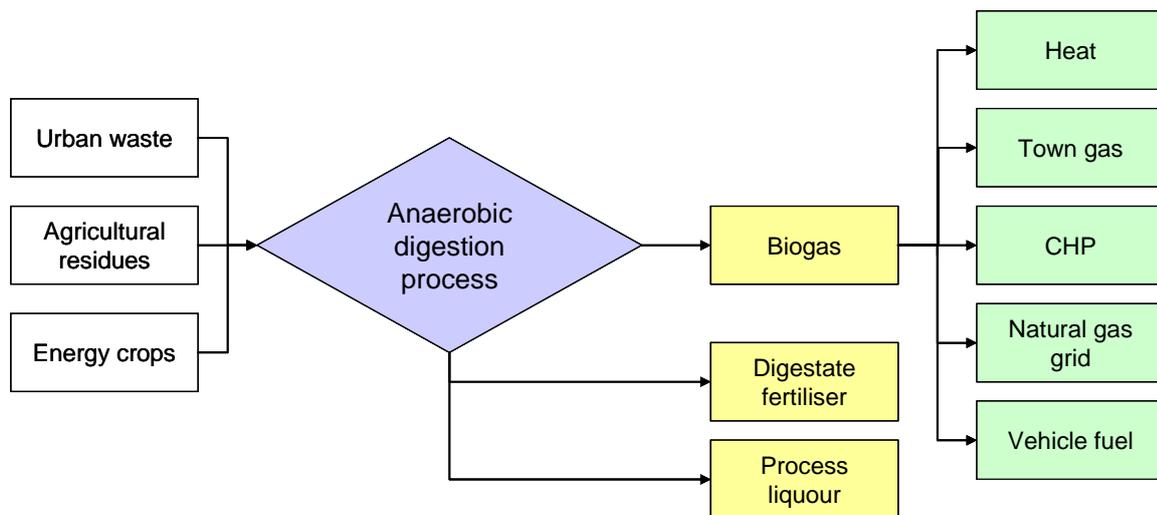
End application:	Required process steps:		
	Pre-treatment	Upgrading	Compression and storage
Flare	Very simple		> 0,1 bar
Town gas for heat	Simple		2 – 4 bar
CHP	Advanced		2 – 4 bar
Natural gas grid	Advanced	Remove CO ₂	Compr. required 4 – 50 bar
Vehicle fuel	Advanced	Remove CO ₂	Compr. & storage 200 – 250 bar



2.2 Challenging issues

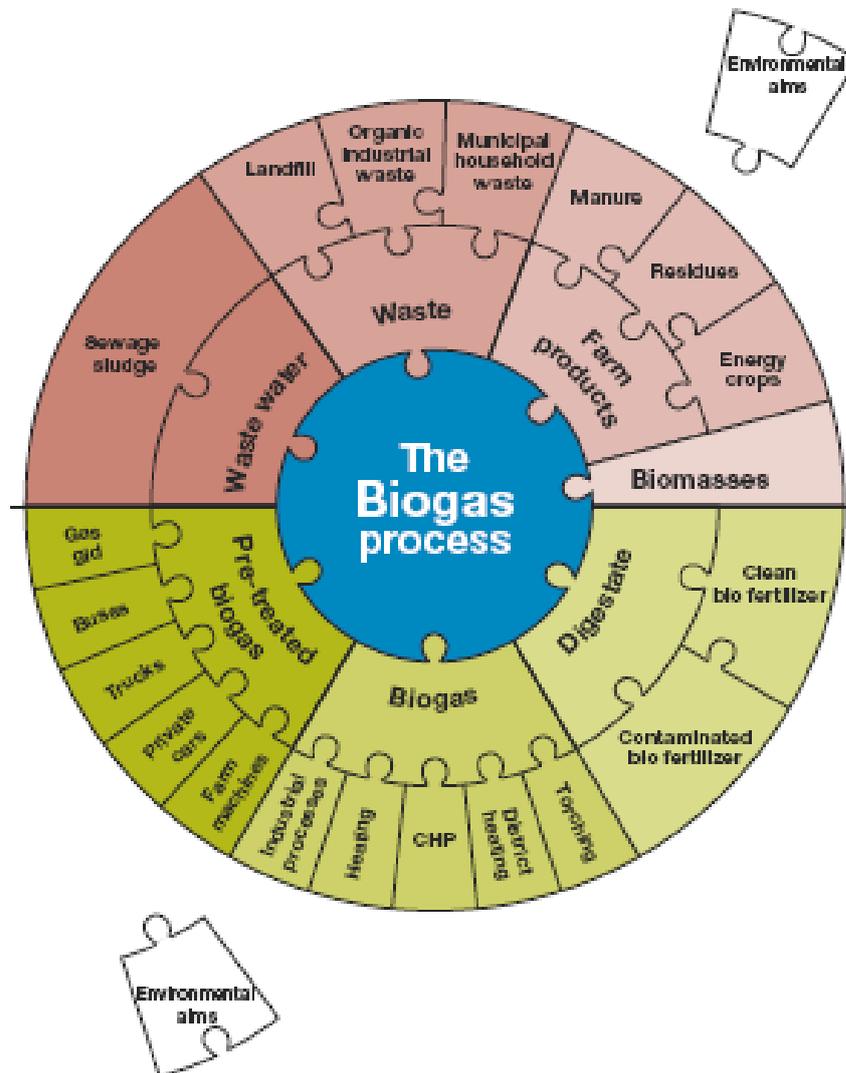
As has been demonstrated in this chapter, biogas can be produced from various raw-materials, which originate either from the urban or from the farm environment (manure, crop residues, energy crops). It was also explained that biogas can have various end-applications in the market ranging from heat production to use of biogas as vehicle fuel. Figure 9 gives an overview of key inputs to the anaerobic digestion process, shows the main outputs and gives a demonstration of the main end-uses of biogas in the energy markets. End-uses of digestate have not been shown in the figure but the environmental benefits of applying digestate (and process liquour) to arable land – which leads to the completion of the full biogas eco-cycle - should not be overlooked.

Figure 9: Inputs to and outputs from anaerobic digestion, including end-applications of biogas



The variety of raw materials used in the anaerobic digestion process, the availability of many different digestion technologies, the need to find an end-application both for the biogas and the digestate produced, as well as the involvement of many actors in the biogas chain from raw-materials sourcing to locating the plant and finding customers for digestate and biogas products make the setting up of anaerobic digestion plants a challenge in itself (Berglund 2006, Khan 2004). In Figure 10 Nylander demonstrates the ‘puzzle-like’ character of biogas production by identifying the various raw material groups (top half of the circle), which through the anaerobic digestion process can be converted into several end-products (lower half of the circle). By adding two separate puzzle pieces for environmental aims, he also demonstrates that environmental aims, such as reduced greenhouse gas emissions or reduced nutrient leaching from arable land, often play an important role when an AD facility is set up.

Figure 10: “Biogas puzzle”



Source and copyright: Anders Nylander (www.nylan.se)

The successful setting up of an anaerobic digestion plant requires:

- Securing the supply of good, clean streams of cheap raw material with high energy production potential.
- Choosing the right technological design for the plant.
- Ensuring that there is sufficient market demand for the chosen end-application of biogas and that distribution infrastructure is in place.
- Making sure that the digestate is of good quality and that preferably local farmers are favourable to its use on arable land.

In practise, these four objectives can only be achieved if the interests of all parties involved in the biogas chain (producers of raw materials, producers of energy, distributors of energy, users of energy and digestate) are taken into consideration before the plant is set up. One should also realise that farmers play a key role in the biogas chain, being both providers of raw

materials, potential consumers of energy (but with a limited need) as well as customers for digestate. More often than not, satisfying the demands of multiple stakeholders and the high initial need for investment finance might require extensive negotiations or some form of a shared ownership of the plant.

2.3 Competing technologies

The reader can use information provided in this chapter to understand how biogas systems compare with competing technologies, and what kind of variables influence the environmental impacts of biogas systems. Some of the latests results on life cycle impacts of selected renewable fuels are presented to allow the reader to put separate facts that different interest groups might utilise in their arguments both in favour and against biogas in a wider context.

Anaerobic digestion is usually primarily considered to be an environmental innovation in the waste management sector. This is due to the fact that anaerobic digestion is normally first applied to waste treatment, before the benefits of this technology for energy production purposes become widely accepted. However, considering that specially grown energy crops represent the largest potential for biogas production, a comparison of anaerobic digestion with the main renewable energy production technologies is also necessary. This is especially so because anaerobic digestion competes for the same raw materials with some other renewable energy technologies.

The following two chapters will discuss the main established technological systems that, to a certain extent, compete with anaerobic digestion as a technology for:

- a. Treating waste
- b. Producing renewable energy

A life cycle analysis on replacing biogas with various reference systems has been referred to in various parts of chapters 2.3.1 and 2.3.2. This study “Environmental systems analysis of biogas systems – Part II: The environmental impact of replacing various reference systems” by Börjesson and Berglund (2006) calculates the environmental impact for biogas systems and other waste treatment and energy production systems, estimating their: global warming potential, eutrophication potential, acidification potential, photochemical oxidant creation potential and emissions of particles, the functional unit being 1MJ energy (heat, heat and power, or kinetic energy referring to transport fuels). In addition, indirect environmental impacts from the production of fertilisers are also taken into consideration. The analysis includes fuel cycle emission from production and the final use of energy carriers as well as indirect environmental effects from changed farming practice and storage of manure, for example. Results from this life-cycle analysis have been complemented by interviews with specialists in the area.

2.3.1 Competing waste treatment technologies

Anaerobic digestion competes with two other waste treatment technologies, namely composting of source separated waste and incineration (with energy recovery) of mixed waste. It is these three waste treatment methods that currently prevail in Europe for the conversion of biodegradable waste away from landfill, an action demanded by the European Union through the 1999 Landfill Directive (Council Directive 1999/31/EC). The main purpose of this directive is to reduce methane (greenhouse gas) emissions resulting from landfill of biodegradable waste.

It should be pointed out that incineration is not widely applied yet in Finland due to the Finnish preference for co-incineration or, more recently, direct gasification of solid recovered fuels (SRF) in industrial and municipal combustion plants. These two technologies do not compete with anaerobic digestion to the same extent as mass incineration of waste, because the fuel they use (SRF) is mainly produced from clean industrial sources of waste with high energy content such as paper, plastic and wood. According to Esa Kurkela (2006), who works as Development Manager in the Technical Research Centre of Finland, a 35-40% electric efficiency can be achieved in waste-to-energy³ plants based on gasification with a total efficiency of 80-85% in combined heat and power production. This implies a 40-50% electricity share and 50-60% heat share of the final energy output. This can be compared with approximately the same overall efficiency (Kurkela 2006), but only a 7.5% electricity and 92.5% heat share of the total energy output in Swedish waste incinerators (RVF 2005c). A larger electricity share could be achieved in Swedish incineration plants, but this is currently not possible because they need to keep low steam temperature and pressure in order to avoid corrosion from chlorine and alkali metals that can be found in the incoming waste (Kurkela 2006).

An advantage of waste gasification as opposed to mass incineration is that it supports materials recovery, since metals and glass need to be sorted away before gasification. Gasification plants also prefer separate collection of biowaste, which however is not absolutely necessary to realize based on the fact that biodegradable wastes can be used as long as the moisture content of the gasifier feedstock does not exceed 35% (Kurkela 2006). The development of these two technologies in Finland has been slowed down due to the coming into force of the EU Waste Incineration Directive (Council Directive 2000/76/EC), a political issue which will not be elaborated in more detail in this report.

Composting systems vs. anaerobic digestion systems

Anaerobic digestion can be considered an environmental innovation in the waste management sector due to the positive environmental aspects related to it. The main benefit of AD in comparison to composting is its positive energy balance. Replacement of fossil fuels with renewable biogas can help curb climate change while providing the owner of the facility with an extra source of income. In the Viikki waste water treatment plant owned by Helsinki Water, biogas covers annually 16,000 MWh of the plant's electricity demand and 27,000 MWh of the heat demand. In financial terms this implies a saving of EUR 1.6 million calculated in current market prices, which are: EUR 50/MWh electricity and EUR 30 / MWh heat (Lundström 2006).

Life cycle analysis carried out by Börjesson & Berglund (2006) shows that when biogas systems replace composting systems, all environmental impacts considered in the study were reduced significantly. Reduction in greenhouse gas emissions resulted mainly from the fact that biogas can be used for the provision of heat, CHP or transportation fuel, whereas composting systems in Finnish and Swedish conditions usually have a negative energy balance (consume energy). To provide the same energy service (1 MJ) as biogas systems, an additional input of fossil fuels is required for composting systems, contributing to the higher global warming potential of composting systems in comparison to biogas systems. Reduction in the eutrophication and acidification potential is also demonstrated to result from better recycling of nitrogen (avoided nitrogen emissions to air and water).

³ Another term used for waste mass incineration plants

As a final point, it should be pointed out that composting also requires the adding of special mixing materials, increasing the amount of compost end-product in comparison to the amount of treated raw material. Digestion, on the contrary, reduces the amount of raw-materials in the process and hygienises waste more effectively than composting, hereby making end-utilization or disposal easier. The EC Animal by-product directive (Commission Regulation EC 1774/2002) demands specific hygienic standards from waste treatment, which are easier to accomplish through digestion than composting.

Börjesson and Berglund (2006) also demonstrate that, in the farm environment, replacing conventional liquid manure with digested manure reduces the environmental impact from treatment of manure in all the environmental impact categories. This implies that digestion should be preferred to conventional storage of manure (manure stored in the pig house for 15 days). Kalmari (2006) also points out that the application of digested manure to pasture land is better for cows than the use of undigested manure, which contains more pathogens. In his farm, the introduction of digestion as a treatment for manure improved the health of the cows resulting in significant increases in milk production.

Waste incineration systems vs. anaerobic digestion systems

The main benefit of AD in comparison to incineration is nutrient recycling. AD recycles all the nutrients in the waste, with the additional advantage of increased soil organic matter content. Incineration, on the contrary, leads to nitrogen emissions and contamination of nutrients by other waste fractions, the end-product of incineration being a toxic ash that needs to be deposited in a landfill for hazardous waste. The energy yield of waste incineration is superior to that of anaerobic digestion. However, the benefit of biogas is that it has multiple end-applications (see Table 2 on page 17). Biogas can, for example, be used for the production of electricity or vehicle fuel whereas incineration is mainly used to produce heat⁴ (92.5% of energy output of Swedish incinerators in 2004) and electricity (7.5% of energy output of Swedish incinerators in 2004) (RVF 2005c).

Life cycle analysis results of the study by Börjesson and Berglund (2006) show that in large scale heat production, incineration systems actually have lower greenhouse gas emissions than biogas systems. This is clearly the case when the raw material used is municipal organic waste. Combustion of food industry waste also leads to lower emissions of greenhouse gases but the difference is not as significant as for municipal organic waste. In other environmental impact categories there are no significant differences between incineration and biogas systems, except for particle emissions, which are greater for incineration.

When comparing AD with digestion, the main waste-to-energy technology AD competes with, one should be aware that incineration is a mature technology whereas anaerobic digestion is still under development. This means that technological development can further increase the energy yield from AD and increase its attractiveness in relation to incineration (and decrease the difference in GHG emissions between the two systems). It should also be mentioned that the benefits of recycling nutrients and soil organic matter through AD have not been fully explored yet.

As a final remark, it is important to point out that AD and incineration can also complement each other as waste treatment alternatives. In Sweden, where waste incineration is common, waste management professionals state that there is enough waste both for digestion and incineration (as well as for the running of a relatively well developed system for recycling glass,

⁴ Waste incineration in Sweden covers 15% of the total district heating demand. (RVF 2005c).

metal and paper). This can be demonstrated by the fact that the current waste incineration capacity is not enough to deal with all the waste produced. In 2004, for example, the amount of stored household waste increased by some 60,000 tonnes (RVF, 2005a, p.5).

2.3.2 Competing energy supply technologies

As explained in the introductory chapter, the existing energy production systems are highly dependent on fossil fuels, even though 20-30% of the total Finnish and Swedish energy supply is based on renewable energy. Therefore, there should not be any real competition between different forms of renewable energy since all possible sources of renewable energy are needed. However, these new technologies do compete in the sense that some of them consume the same raw materials, for the growing of which there is only a limited field area. In addition, one should bear in mind that different sources of renewable energy compete for a priority position in government policies favourable to renewable fuels. Government policies will be discussed in more detail in chapters 3.1 and 3.2.

Biogas systems replacing systems based on fossil fuels

As the life cycle analysis by Börjesson & Berglund (2006) shows, the replacement of fossil fuels with biogas can lead to significant reductions in greenhouse gas emissions. In the case of replacing *heat production* based on fuel oil, for example, these reductions are in the range of 75-90% per MJ energy service depending on the raw material digested (primary energy input). In *combined heat and power production* this reduction is similar to that of heat production. However, the use of natural gas as fuel in the CHP reference system makes the benefit of this reduction slightly smaller. In the transport sector global warming potential will normally be reduced by 50-85% when biogas replaces petrol and diesel as a transportation fuel. (Börjesson & Berglund 2005).

Biogas systems replacing other renewable energy systems

According to Börjesson & Berglund (2005), replacing other renewable energy systems with biogas systems is not always as clearly environmentally justifiable as replacing energy systems based on fossil fuels. In what follows, replacing different renewable energy systems with biogas systems will be considered for the following forms of energy: heat, combined heat and power (CHP), and transport fuels.

When biogas replaces biomass based *heat production* greenhouse gas emissions can increase significantly, “by approximately 50-500% when replacing combustion of willow [and organic waste]” (Börjesson & Berglund 2006). The main reason behind these results is the lower heat output of biogas per tonne of raw material in comparison with combustion. The advantage of biogas in comparison to other heat systems based on renewable energy is that its use for heat production reduces emissions of particles by between 30-70%, and even by 90% in the case of replacing combustion of straw with biogas. Combustion of energy crops also results in higher photochemical oxidant creation potential than biogas based heat production (Börjesson & Berglund 2005).

When biogas systems replace other renewable energy systems for *CHP production*, the results are expected to be similar to those of heat production alone, i.e. greenhouse gas emissions from biogas systems are higher than those from reference systems. This statement is confirmed by both Kurkela (2006) and Kåberger (2006), who point out that in CHP systems the use of dedicated energy crops for biogas production is not as efficient as their direct combustion in a CHP plant. While this is true, one should bear in mind that the environmental advantage of biogas is that many different crops can be used to make biogas.

According to Rintala (2006), this is an important advantage of biogas as opposed to combustion of biomass, which requires specific crops to be used. Cultivation of various crops instead of monocultures supports biodiversity and helps reduce the use of pesticides (pesticides are needed more in monocultures). Additionally, as is the case for heat production, emissions of particles and the photo oxidant creation potential are higher for combustion of energy crops than for biogas systems.

The life cycle analysis by Börjesson & Berglund (2006) does not draw extensive conclusions on the environmental impacts with regard to replacing other renewable *transport fuel* systems with biogas systems. However, it might be the case that, contrary to the results of the official government inquiry on alternative fuels from 1996 (SOU 1996:184), biogas might actually not be the cleanest fuel in the market if its total lifecycle emissions are considered (the 1996 study considered mostly the emissions from end-use assuming that other emissions were not significant). Results of the lifecycle analysis by Börjesson & Berglund (2005) show that: “using ley crop-based biogas to replace methanol from willow is calculated to increase the greenhouse gas emissions by 30-50%, mainly due to the need for additional petrol or diesel in the biogas system to compensate for the lower energy output per hectare”.

Another report by Helmfrid and Haden (2006) indicates that AD could be the most efficient production technology for car fuels in Swedish conditions. They estimate the land area needed for production of renewable fuels to replace the current consumption of diesel and gasoline to be: 4 million hectares for biogas production; 6 million hectares for the production of an equivalent amount of ethanol from wheat and RME from rape seed; or 15 million hectares of forestland to replace this consumption by converting wood into ethanol or DME and/or methanol (Helmfrid & Haden 2006). Börjesson’s research (Börjesson 2004) supports this argument, demonstrating that it is more efficient to use wheat for the production of biogas than for ethanol production. In Sweden, where domestic production of ethanol takes place, this is an important observation.

In Finland, on the other hand, the situation is quite different. Ethanol is not really considered a potential alternative for producing domestic biofuels. One ‘domestic-produce’ biofuel plant is currently under construction in Finland. This plant, which is being built by Neste, will produce biodiesel from bio-oils using the so-called NExBTL process (pilot work done, plant to start operations in summer 2007 in Porvoo) (Hodge 2006). Malkamäki (2006) believes that this is a promising alternative for biofuels production in Finland. The potential weakness of this alternative is that the required size of production facility is so big that it is difficult to cover the raw material demand using domestic raw materials. The import of raw materials can significantly increase the NExBTL diesel price due to elevated transportation costs.

New renewable energy technologies

The reader should be aware that some new technologies are currently at the demonstration phase for the gasification of biomass into synthesis gas, which consists of carbon monoxide and hydrogen, and can be further converted into various liquid and gaseous energy carriers. The estimated conversion efficiencies for selected end-products from gasification of biomass have been summarised in Table 3. In Sweden, gasification technology is developed in the Värnamo gasification plant, which includes the EU subsidised CHRISGAS project. In Finland, the Finnish technical research centre is developing gasification technology in cooperation with industrial actors and in Germany a 45 MW demonstration project using Choren gasification technology is up and running (Kurkela 2006).

Table 3: Estimated conversion efficiencies for key end-products from biomass gasification

End-product	Conversion efficiency	Source
Hydrogen gas ¹	70%	Kurkela 2006
Synthetic natural gas (methane)	65% (lower than current efficiency for direct combustion)	Börjesson 2006, Kurkela 2006
DME (Dimethyl Ether) ²	58%	Börjesson 2006
Methanol ³	58%	Börjesson 2006
Fischer Tropsch Diesel	52% - 85% (depending on utilisation rate of fuel gas and steam)	Kurkela 2006

¹) Transition to the hydrogen economy is complicated by technological challenges with regard to distribution and end utilisation of hydrogen, which is a highly reactive gas.

²) Clean burning alternative to liquefied petroleum gas, liquefied natural gas, diesel and petrol.

³) Toxic, and does not function well as car fuel in cold climates but can be used to produce renewable MTBE - oxygenate added to petrol to increase its octane rating.

According to Börjesson (2006), gasification technology is also a good option for producing car fuels. His research shows that in Southern Swedish conditions, the best future alternative is salix derived biomethane produced using gasification technology, which provides a 57,000 km transport service, followed by salix derived methanol or DME for conventional engines (49,000 km). If one, in addition, were to apply new more efficient hybrid technology for the car, the efficiency could be almost doubled for all the afore-mentioned fuels (Börjesson 2006). In Finland the production of Fischer Tropsch Diesel through gasification technology is a promising alternative if the production plant is located in pulp and paper industry or another industry with a high heat demand (Kurkela 2006). This fuel can be used as such to run conventional diesel engines. This is in contrast to many biofuels, which can only be blended with fossil fuels up to a certain proportion without the need for changes in engine technology (e.g. max. 15% ethanol in petrol).

With regard to the use of biogas for vehicle fuel purpose, one should bear in mind that the existing production, distribution and consumption systems for vehicle fuels are designed for liquid fuels. The use of biogas as vehicle fuel is slowed down by the high initial investment costs in production and, especially, distribution infrastructure, as well as the fact that consumers wanting to use renewable methane gas to run their car need to invest in a new car with a conversion technology suitable for this type of fuel. The current systems infrastructure is more supportive towards distribution of liquid biofuels.

Summary

The key message from this chapter is that biogas systems offer a variety of environmental benefits. Hence, no hastily made conclusions based on only one environmental indicator should be made. Instead, the benefits of biogas systems should be considered from a wider systems perspective where the indirect environmental impacts of, for example, nutrient and soil organic matter recycling or higher biodiversity should also be taken into account. However, little research has currently been carried out on these aspects of biogas production.

Overall, digestion can be seen as a superior alternative to central composting (home composting schemes might be preferable in areas with long transport distances). Digestion can also be seen as a solution that can complement incineration as a waste management alternative to provide a more varied range of final energy services. Further improvements in the energy conversion efficiency of AD technology and wider understanding of its indirect environmental benefits (as new environmental problems such as decline in soil fertility are identified or prices of chemical fertilisers go up) might further increase the attractiveness of this technology in the future.

When biogas systems replace conventional systems based on fossil fuels significant reductions in greenhouse gas emissions can be achieved. However, when biogas systems replace other renewable energy systems greenhouse gas emissions usually increase. This should not act to hinder the implementation of biogas systems as part of a balanced and diversified supply of renewable energy in Finland and Sweden. It should also once more be emphasised that biogas systems serve multiple environmental purposes, an aspect which is easy to ignore but might receive higher attention in the future as new environmental problems appear (e.g. decline in biodiversity and increase in the use of pesticides due to the increased amount of land area being dedicated to specific high energy crops).

Chapter 3 will now analyse how the social, political and techno-economic sub-systems in Sweden and Finland have influenced the implementation of AD as an environmental innovation in the waste and energy sectors. On the basis of this analysis, the main drivers or barriers to AD technology in both countries will be identified. The country results will then be compared in chapter 4 to provide an answer to **Research Question 1**: “What factors have contributed to a much earlier and extensive development of biogas production in Sweden as compared to Finland?” Recommendations and reflections to Finnish policy makers are provided in chapter 5 in order to answer **Research Question 2**: “What lessons could Finland learn from the Swedish biogas development in order to develop its own comprehensive strategy and design suitable policy approaches?”

3 Diffusion of biogas systems in Sweden and Finland

AD technology is one of the three prevailing technologies used in Europe for the diversion of biodegradable waste away from landfills. Usually AD goes through the following two development phases: (i) anaerobic digestion develops from a technology mainly used to reduce sludge volumes in municipal sewage treatment plants or in treating manure, to a technology for the treatment of organic waste from industry and households; (ii) AD develops from a waste treatment technology to a technology that is considered one of the many alternatives for the production of renewable energy, not only from waste but also from energy crops.

The key focus of the two country case studies is to analyse what factors have from the 1960s to the present driven or hindered the development of AD towards a technology that can be used for the production of renewable energy for *commercial purposes*. The country case studies are divided into three sections consisting of the following time periods: 1960-1980, 1980-1995, and 1995-2006 – the last period starting from 1995 when both Finland and Sweden became members of the EU. Each section will be finished with a small conclusion (in a blue box), which explains the key results of the chapter using terminology presented by Sartorius & Zundel (2005) in “Time strategies, Innovation, and Environmental Policy”. It will be concluded whether, during the time period in question, a window of opportunity for anaerobic digestion opened in any of the three societal subsystems that are of interest to our research, namely the socio-cultural, political and techno-economic subsystems. It will also be explained whether these windows of opportunity were utilised to the advantage of anaerobic digestion technology, and if not, why this was so.

3.1 Sweden

During the 1960s AD appeared as a technology for the treatment of sewage sludge in waste water treatment plants (WWTP). During the 1970s AD spread further to pulp and paper mills, and sugar refineries. Small-scale plants were also constructed for the treatment of manure in farms. All of these developments (apart from WWTP) were relatively small in scale. During the 1980s collection of landfill gas was initiated and so were R&D efforts to further develop AD technology. During the early 1990s, development of biogas systems for vehicle fuel purposes (commercial application) was initiated with the support of the Swedish government and car industry, and since 1995 when Sweden became a member of the EU many co-digestion plants have started operations with varying input of raw materials. Increases in biogas production have been accompanied by the development of system infrastructure to secure that biogas and digestate both find productive end-uses.

3.1.1 1960s to 1970s: AD develops as a method for treating liquid waste

In Sweden, the generation of household waste began to increase significantly during the 1950s and 1960s. This increase in waste generation was mainly due to the introduction of packaged and ready-made products, which not only led to the increase in the weight but even more so in the volume of waste generated and landfilled. Large cities with limited landfill capacity faced the biggest dilemma concerning end-disposal of waste, and incineration was seen as a way of reducing landfill of waste. At that time, anaerobic digestion was not considered an alternative to incineration (incineration technology was already in use in Sweden at the time) for the treatment of municipal solid waste, since its implementation for the reduction of sewage

sludge volumes had only just commenced in municipal waste water treatment plants during the 1960s.

The oil crises of the 1970s started a political discussion over the need to find renewable domestic energy sources, which can be identified as one of the key driving forces for the building of new incineration capacity (incineration with energy recovery). According to Bramryd (2006), prior to the oil crises, there were only two incinerators in operation in Sweden, one in Stockholm and the other one in Linköping.⁵ By the mid-1970s thirteen incineration plants were already in operation in Sweden dealing with some 0.8 million tonnes of mixed waste (RVF 2003).

According to the Swedish Biogas Association (2004), the 1970s energy crises resulted not only in the building of new incineration capacity but also in the research and development of biogas techniques, which caused the further implementation of anaerobic digestion technology for waste water treatment in pulp and paper mills, and sugar refineries. Small-scale plants were also constructed for the treatment of manure in farms. In other words, AD was further applied to new types of biodegradable waste with low total solids content. Even though some effort was put into developing AD technology further as a result of the energy crises, even more effort was put into the development of other types of energy supply technologies such as hydro and biomass, which have a higher potential in Swedish conditions.

The first attempts to reduce the amount of waste going to landfill through recycling and biological treatment (composting) took place in the early 1970s. As part of these efforts twenty composting facilities were built during the early 1970s. The technology applied in these early composting facilities was mechanical after-sorting of the biodegradable fraction of mixed waste. Due to the contact of organic waste with other 'dirty' waste fractions prior to mechanical sorting, contamination of the composted fraction was experienced. This meant that the compost had limited end-uses other than landfill, which led to the failing of these early composting attempts and the close-down of the first composting facilities in Sweden (Bramryd 2006). Nowadays, composting is considered a good alternative for sparsely populated areas (home composting encouraged) or for treating park and garden waste.

It was also during the 1970s that biogas was 'publicly' discovered for the first time. This was due to the introduction of specially designed vehicles for the compaction of waste in landfill. Up until then landfills had been operated under aerobic conditions. This situation changed with the introduction of waste compaction, which led to the creation of anaerobic conditions in landfills, which are a necessary condition for the formation of biogas. This new landfill management technique led to the discovery of biogas in quite a dramatic manner when a landfill explosion took place in Göteborg in the mid-1970s (Bramryd 2006). This constituted a potential window of opportunity for anaerobic digestion in the socio-cultural subsystem. People became aware that landfill of biodegradable waste can be dangerous and that some form of alternative treatment would be preferable. However, this window of opportunity was actually utilized in favour of incineration technology which at the time was a more mature waste treatment technology than anaerobic digestion.

In conclusion, it can be said that up until the 1970s waste was considered a resource that could, for example, be used for 'land filling' – to take more land area from the sea. In the 1970s, however, the problems related to the landfill of waste (the dominating waste disposal technology back then) became better known through the efforts of environmental groups and

⁵ Having mentioned Linköping, it is interesting to mention that this municipality in nowadays considered one of the best and biggest biogas municipalities in Sweden.

through events such as the Göteborg landfill explosion (Bramryd 2006). The early attempts to divert waste away from landfill through increased recycling and biological treatment failed, leading to the general acceptance of incineration as the most promising new technology for the diversion of waste away from landfill. Incineration also had the additional advantage of providing a source of locally produced energy that could be used to run the local district heating networks. Meanwhile, AD was only applied to liquid fractions of biodegradable waste.

Using the terms presented by Sartorius & Zundel (2005) the essence of the 1960 and 1970s would be that the socio-cultural window of opportunity, as resulted from environmental problems with landfill and the need to divert waste away from landfill, was utilised to the benefit of incineration. An additional push to incineration and other selected forms of renewable energy (not biogas as a commercial application for energy production) was provided by the 1970s oil crises.

3.1.2 1980-1995: Research, development and demonstration of AD as an energy technology

In the 1980s the political will opened up for the seeking of alternatives to incineration, mainly due to the public health concerns related to the air emissions from incineration. The main concern was dioxins, human carcinogens which can also cause disruption of reproductive, endocrine and immune systems (Miller 2005). The presence of these harmful chlorinated hydrocarbons in the incineration ash was discovered in the late 1970s (RVF 2003). This again constituted a window of opportunity in the socio-cultural subsystem for the development of alternative waste treatment methods such as AD. As a result of this 'dioxin-scare', the government placed a moratorium on the construction of new waste incinerators in 1985. During this moratorium, an enquiry into the environmental impacts of waste incineration was carried out, and when the results of this enquiry were released in 1986 the moratorium was lifted (Smith 2006).

The end-result of the dioxin-scare was the establishment of a set of stringent emission regulations that incineration plants had to comply to with. In practice, this meant that, of the 27 incineration plants in operation in 1985 20 installed advanced flue gas cleansing systems and 7 plants were closed down due to environmental or economic reasons. The dioxin scare gave incineration a very bad public image and slowed down the construction of new facilities during the rest of the 1980s. However, the already existing incineration plants continued to improve their flue gas treatment systems and the efficiency of the energy recovery from incineration (RVF 2003, Smith 2006). As a result of these early efforts, Sweden nowadays has the highest energy recovery rate of waste in Europe, 2.9 MWh per tonne of waste (RVF 2003, RVF 2005a). In other words, the political subsystem did react to the pressure from the socio-cultural subsystem based on the dioxin scare, but this alone was not enough to shift the key focus away from waste incineration towards alternative treatment alternatives.

The political will of the 1980s to find alternatives to incineration and landfill of waste materialised into research programmes, operated by the Swedish Environmental Protection Agency. One of these early research programmes was run in cooperation with the Swedish Board of Energy, and investigated the possibility of using biocells, an advanced landfill technique where biogas and leachate production occur under controlled conditions for the production of biogas. The biggest research projects were carried out in Malmö and Helsingborg, where the first 'biogas plant' was actually a biocell producing 12 MWh annually for district heating. In 1985 the first landfill also started the collection of landfill gas, setting an example that was soon followed by other landfill operators. The interest in biogas was by then

well established due to the purity of biogas as a fuel (Bramryd 2006). It should, however, be pointed out that the implementation of landfill gas collection systems is in no way related to the development of AD technology as such because it is just an end-of-pipe method for dealing with methane emissions from landfills.

It should be mentioned here that the Swedish government was during the 1980s not only looking for alternatives to incineration but also for ways of substituting nuclear power with other forms of energy. This was due to the decision taken by the Swedish government in 1980 that nuclear power was to be gradually phased out in Sweden by 2010 (a target which seems highly unrealistic at present). In addition, the energy crises of the 1970s had demonstrated that new forms of domestic energy were needed to secure the energy supply in times of crisis, including times when fuel prices increase dramatically within a short time period.

By the end of the 1980s climate change had also become a concern at international level, demonstrated by the establishment of the Intergovernmental Panel on Climate Change in 1988. Politicians in Sweden were relatively well informed on the causes and impacts of climate change due to the early engagement of the Swedish scientific community in climate change related research. The Swedish chemist, Svante Arrhenius, had been among the first to suggest, as early as in 1896, that the burning of coal and oil based fuels would lead to the warming of global climate (UNEP World Conservation Monitoring Centre 2006). Another Swedish climate researcher, Bert Bohlin, is one of the individuals whose research and educational work on climate change, dating back to the 1950s, led to the establishment of the Intergovernmental Panel on Climate Change. As has already been mentioned, development of renewable energy sources such as biogas can be identified as one way of combating climate change.

It can be concluded that during the 1980s a political window of opportunity opened for biogas because the government wanted to pursue multiple strategies: look for alternatives to incineration as a waste management solution; reduce dependence on energy imports to reduce the potential economic impacts of yet another energy crisis; substitute nuclear power with other sources of energy; and combat climate change.

By the beginning of the 1990s anaerobic digestion technology had developed to such an extent that the first specialised co-digestion plants started to be built (as opposed to municipal sewage sludge digesters, which would occasionally co-digest other organic waste fractions). Planning of a number of co-digestion plants took place during the first half of the 1990s, and most plants started operations from the mid-1990s onwards. In most cases the plants were, and still are, owned by the municipal waste management, waste water treatment and energy companies. In addition, the food industry and local farmers have often acted as co-owners of the plant because of their important role in creating a steady supply of raw materials and a demand for digestate.

It seems to have been clear to the municipalities from the very beginning that the main end-application of biogas would be vehicle fuel. This is probably due to the fact that government actions gave the municipalities an incentive to implement systems geared towards this specific end-use application. This argument can be supported by the fact that in 1991 the Swedish Transport & Communications Research Board (KFB⁶) launched a programme to demonstrate the use of biogas and ethanol as biofuels for buses, heavy duty vehicles and cars. The results of these demonstration projects, which were carried out in Stockholm, Trollhättan, Linköping and Uppsala, were positive, and other municipalities followed their lead. The municipality of

⁶ Nowadays KFB operates under The Swedish Governmental Agency for Innovation Systems, VINNOVA

Kristianstad, which has received many awards for its environmental and climate work from 2000 onwards, is one of the municipalities that have been encouraged by the positive examples of Trollhättan and Linköping (Erfors 2006).

Government finance was available for the first Swedish biogas plants. Trollhättan, being part of the pilot programme for the transport application of biogas, for example, received a significant amount of money from the KFB. The grant they received covered 50% of the estimated investment costs for infrastructure, including: upgrading, gas delivery, compressor, refueling station and buses. Due to slightly higher costs than expected the grant finally covered 42% of the capital costs. (Svensson, 2006)

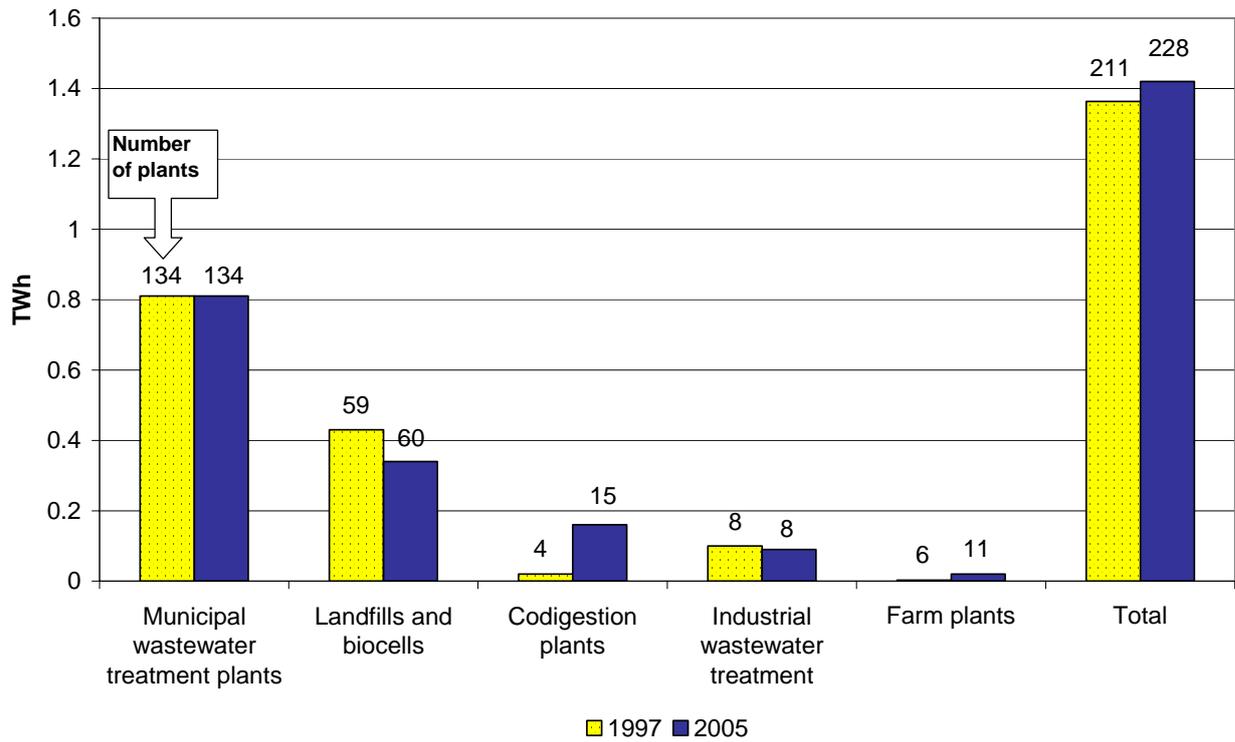
As a last remark it should be mentioned that the existence of a large automotive industry in the country might have given Sweden an added incentive to look into the use of biogas as a vehicle fuel, while other countries (e.g. Denmark and Germany) are mainly using it for the production of heat and electricity. The enthusiasm of the car industry to develop engine technologies suitable for biogas might have influenced the government's decision to use biogas as a vehicle fuel. The positive aspect of having a clearly preferred government alternative for end-use application of biogas from the very beginning is that different actors have felt confident about investing in biogas infrastructure. This systems development, especially the building of new distribution infrastructure, has been especially important for increasing the utilisation rates of the biogas produced, as opposed to flaring it off.

It can be concluded that between 1990 and 1995 the political window of opportunity, which had opened for biogas production during the 1980s as a result of the government reacting to environmental and other pressures in the waste management and energy sectors, was utilised in favour of anaerobic digestion technology. The political will to support biogas production most probably materialised itself into programmes in the transport sector due to the positive attitude of the Swedish automotive industry towards the end-use application of biogas as vehicle fuel.

3.1.3 1995-2006: Environmental policy drives biogas systems development

From 1995 onwards the building of co-digestion plants sped up. As can be seen from Figure 11, biogas production in municipal & industrial waste water treatment plants and in landfills stagnated between 1997 and 2005, while the biggest increase in production occurred in co-digestion and, to a more limited extent, farm plants. We will now proceed to analyse how the actions taken by the political subsystem have since 1995 influenced the socio-economic subsystem where AD technology is implemented. It should be pointed out that prior to 1995 a window of opportunity for AD had already been identified in each of the three societal subsystems (socio-cultural, political and techno-economic). Hence, now it is more a case of analyzing whether AD will be able to succeed in its own right in the market as a technology, that can contribute to the achievement of multiple environmental objectives.

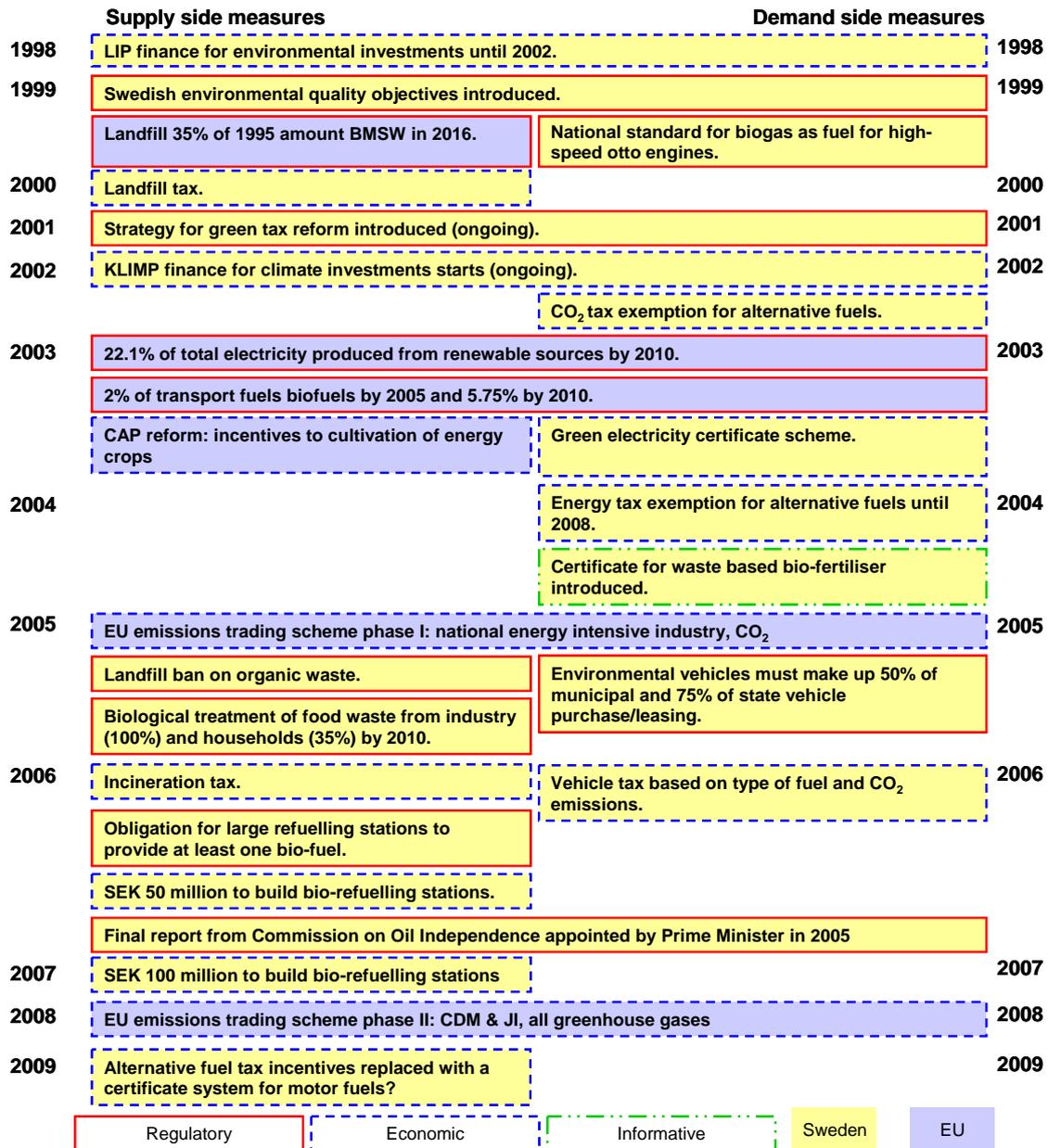
Figure 11: Biogas production and number of facilities in Sweden, 1997 and 2005



Sources: Lindberg 1997, Berglund 2006 p.8, RVF 2006, Persson 2006

The government policies, which since 1995 have contributed to the development of biogas production, have been summarised in Figure 12, differentiating between: year of introduction of the policy instrument; policy owner (EU, Sweden); type of policy instrument used (regulatory, economic, informative); and whether the instrument is geared towards creating more supply or demand for biogas (demand side measures, supply side measures). It should be pointed out that from this point onwards we are concentrating on describing in more detail how the political subsystem has influenced the techno-economic subsystem where the environmental innovation is implemented.

Figure 12: Swedish political subsystem - policies affecting demand and supply of biogas since Sweden became EU member in 1995



The impact of waste policies on the development of biogas systems has until 2005 been relatively low in Sweden. The EC landfill directive of 1999 has, due to its neutral position on ways to achieve diversion of waste away from landfill, had little influence in the development of biogas production in Sweden. In the national context, no specific demands for biological treatment of organic waste were set either until 2005 when national targets for biological treatment of foodwaste from industry and households were introduced, which were followed by the introduction of an incineration tax in 2006. However, these developments in waste management are too recent to have influenced the initial wave for the building of co-digestion plants. It can therefore be concluded that the development of biogas systems from 1995 onwards has been driven by other than waste policies. Other policies will be considered in continuation.

The environmental policy can be identified as one of the main drivers for the development of biogas systems in Sweden, due to its impact on other government policy areas. The Swedish environmental policy is based on a set of environmental quality objectives that were introduced in 1999. The purpose of these objectives is described in more detail in the box below.

Swedish environmental quality objectives

In 1999 the Swedish government adopted 15 national environmental quality objectives complemented with a final sixteenth objective in 2004. These objectives replaced all the environmental objectives previously adopted by the parliament, government agencies having shared responsibility over their implementation (Government bill 2000/01:130). The government aimed to prioritise measures, that help to achieve several environmental quality objectives at the same time, with climate policy highest on the agenda. This requirement can be seen as favourable to biogas systems because they contribute to the achievement of multiple environmental quality objectives (see Appendix 6 for more information), including objective number one: “reduced climate impact”. A separate Swedish Climate Strategy Bill was adopted in 2001 for the purpose of implementing this objective. The Climate Strategy Bill states that, even though the implementation of the Kyoto protocol inside EU would entitle Sweden to increase its emissions of carbon dioxide by 4%, Sweden would actually reduce its greenhouse gas emissions by at least 4% by 2010 without any compensation for uptake in carbon sinks or by use of flexible mechanisms⁷ (Summary Government Bill 2001/02:55, p. 2).

In addition to transferring the responsibility for environmental issues to various sectors of public governance – using the environmental quality objectives as a tool – the government is also aiming to “make municipalities the motor of ecological changeover in Sweden” (Naturvårdsverket 2005b). This aim is promoted through the provision of investment finance to municipally driven projects. The Local Investment Programme (‘LIP’) between 1998-2002 and Climate Investment Programme (‘KLIMP’) from 2002 onwards have given municipalities the opportunity to (i) analyse the environmental situation in the region, (ii) define projects to reduce their environmental impact and (iii) get finance for their projects to reduce their environmental (LIP) and climate (KLIMP) impact.

Investment subsidies

In practice, many of the successful LIP and KLIMP applications concentrated on the development of biogas infrastructure. This includes not only the building of anaerobic digestion facilities but also the adjoining infrastructure. In 2005, for example, 40% of the KLIMP grants (MSEK 127 out of MSEK 317 million) were awarded to biogas projects (Naturvårdsverket, 5 May 2006). This translates to between 20-30% of the total investment cost for a single project. The fact that municipalities coordinate the applications for KLIMP finance can probably partially explain why a lot of the finance has been directed to municipally owned entities such as municipal waste management and energy companies, rather than, for example, developing biogas infrastructure in the farms.

Because the KLIMP programme financed projects are still under implementation, no evaluation of them has been conducted for the time being. An evaluation of the impacts of the LIP grants, however, was carried out in 2005. This evaluation concluded that, even though the

⁷ According to the latest projections, Sweden will be able to reduce its GHG emissions by 2% by 2010 (Swedish Environmental Objectives Council 2006, p.16). This reduction is below the national target but still expected to be better than EU average.

decreased GHG emissions per awarded sum to AD plants were limited at the time of the evaluation, the avoided emissions from future use of biogas as vehicle fuel were expected to be significant. The evaluation estimated the cost of reduced greenhouse gas emissions per awarded sum (not total investment) to reach 3kg CO₂ equivalent/SEK (approx. EUR36 per tonne CO₂ equivalent) once all AD plants are in full operation (assuming a 15 year operational life) (Naturvårdsverket 2005a). This price can be compared with the price of EU allowances currently varying between 15-20 euros (www.pointcarbon.com).⁸

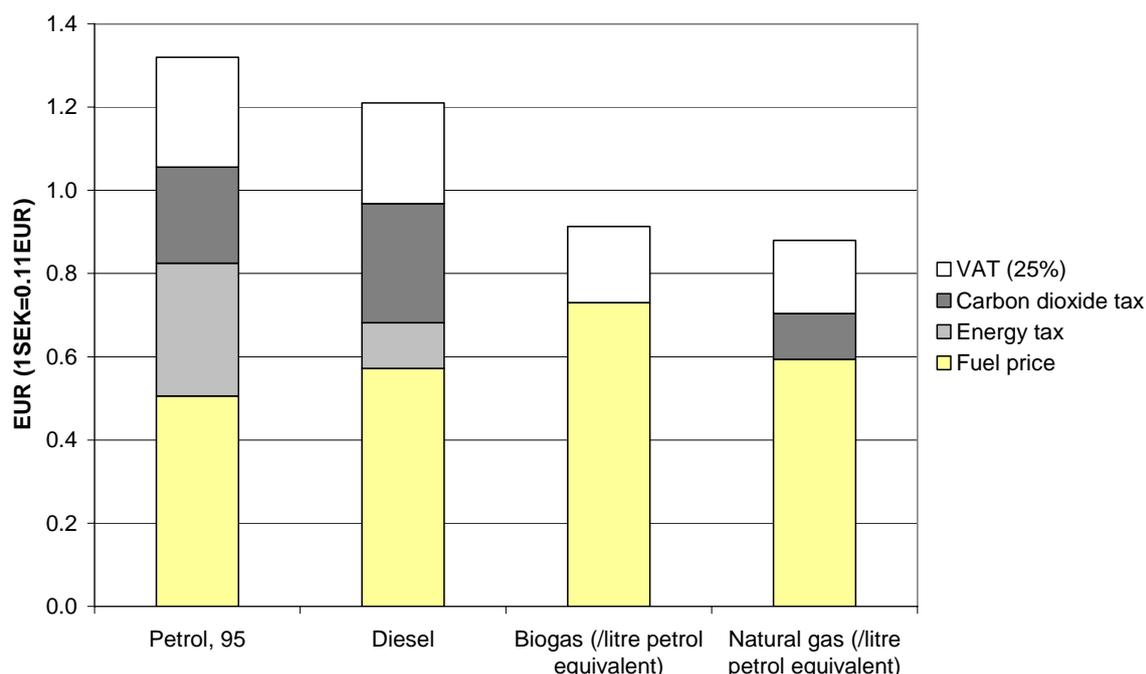
Some Finnish actors are of the opinion that because climate change is a global problem, emissions reductions should be achieved where this is most economical, i.e. through the use of Joint Implementation and Clean Development Mechanism under the Kyoto Protocol. Sweden, on the other hand, has specifically stated that it would not make use of these mechanisms in achieving its greenhouse gas emission reductions. One should bear in mind that the implementation of biogas systems is not only a way of reducing GHG emissions but also a way of providing new business opportunities and creating employment at the regional level, meaning that the KLIMP subsidies do not have to be considered only as a cost but also as an investment in regional development.

Production incentives

In addition to the environmental investment subsidies, which decrease the initial capital risk, the Green Tax Reform from 2001 onwards has played an important role in the widening of a window of opportunity in the techno-economic subsystem for AD. Before 2001, Sweden had already introduced some environmentally motivated taxes, such as the 1991 CO₂ tax. However, it is from 2001 onwards that the Swedish government has made consistent progress to increase environmental taxes while reducing income taxes with an equivalent amount so as to keep the fiscal income the same. We will now look in more detail how biogas as (i) vehicle fuel and (ii) fuel used in electricity production has been supported through government policies.

⁸ This price is expected to increase with the application of stricter emission caps.

Figure 13: Swedish vehicle fuels price composition, June 2006



Source: *Fordonsgas 2006*, *Swedish Petroleum Institute 2006*

Biogas for vehicle fuel – The green tax reform was introduced in 2001, two years before the coming into force of the EU transport biofuels directive (Commission Directive 2003/30/EC). The current end-prices of vehicle fuels are shown in Figure 13, which demonstrates the impact of the 2002 CO₂ tax exemption and the 2004 energy tax exemption for alternative fuels in the end price of biogas in comparison to fossil fuels.

The transport biofuels directive has set a 5.75% target for transport biofuels by 2010. In 2004 domestic production capacity of transport biofuels covered 0.8% of the total consumption in 2004 (SOU 2004:4). Further tax reliefs are not considered a possibility for increasing the market share of renewable transport fuels due to the fact that their lower tax level has not only compensated for the additional production costs, but also given renewables some additional price advantage over conventional fuels. In practice this has “led to a relatively substantial overcompensation for imported ethanol used in low level blending [while] the [EC] energy tax directive, article 16.3, states that overcompensation is not allowed”⁹ (SOU 2004:133, p.29) Therefore, the Swedish government is considering the use of green certificates from 2009 onwards to further increase the share of biofuels in the transport sector.

Biogas for electricity – In 2001 the so-called RES-E directive (Commission Directive (2001/77/EC) came into force setting a 22.1% EU wide target for electricity produced from renewable energy sources. However, the Swedish target by EU was set even higher than that, demanding a 60% share for renewable electricity in Sweden in 2010. This can be compared with an actual 49.1% renewable electricity share in 1997 (Kåberger et al. 2004), which is a high figure in the European context. In Sweden electricity consumption, rather than production, is subject to taxation. This means that renewable fuels are not promoted through fiscal incentives at the electricity production stage. In 2003, the Swedish government introduced Green Electricity Certificates as a means of increasing the share of green electricity. These

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electricity certificates create a market for renewable energy by stating that each year a specific percentage of electricity used must be from renewable sources. Producers of renewable energy receive one electricity certificate for each MWh produced, which they then sell to users of electricity who, under their quota obligation, must purchase a certain amount of their annual consumption of energy from renewable sources. In addition to this, the producers of renewable energy get income from sales of electricity (Swedish Energy Agency 2006). During 2004, the average price of electricity certificates in the market was SEK 231/MWh (or 0.231SEK/kWh), which is equal to 2.5€/kWh.

Network tariffs are part of the final electricity price paid by consumers. In Sweden, the electricity network is currently a monopoly, making access to the grid potentially expensive of small producers. This might not have been considered a problem in Sweden thus far, as biogas is mostly used for vehicle fuel and provision of district heating, electricity produced having been used to cover producer's own electricity demand. It should also be pointed out that by the electricity act, network tariffs must be reasonable and constituted on an impartial basis. The Energy Markets Inspectorate is responsible for the monitoring of network tariffs and can examine their reasonableness (SEA 2006).

Other measures facilitating market penetration of biogas

The Swedish government has opted to support the afore described economic instruments with certain other measures, such as the setting of targets for the amount of state and municipal cars that should be classified as environmental vehicles starting from 2005, or by obliging large refueling stations to offer at least one biofuel as has been the case since the beginning of 2006 (government investment finance totaling SEK 150 million has been set aside for this purpose for 2006 and 2007). Both of these measures can be seen as additional means of influencing the supply and demand of biogas in the markets. These kind of measures have also been taken on behalf of many municipalities, who for example: cover part of the cost for purchases of environmental cars to make up for the otherwise higher investment costs for the car owner (finance from KLIMP possible); provide free-parking for environmental vehicles or, as is the case for Stockholm, waiver the congestion charge for environmental vehicles. In addition, municipal decisions concerning, for instance, investments in biogas driven buses for public transport can also create end-markets for biogas.

Impact of government policies on diffusion of AD

The initial government (and municipal) support can be claimed to have given biogas systems an opportunity to compete on a more equal basis with more established technologies, which can benefit from the so-called path dependence effect (Sartorius & Zundel 2005, described in chapter 1.5). Competitiveness of anaerobic digestion in the market place has, indeed, increased over the past ten years. In Linköping, for example, the raw-gas yield per tonne of waste digested has more than doubled from 65m³ five years ago to 155m³ today. According to Cook (2006), the Linköping plant is one of the best in Sweden, operating well above the average 1-2m³ raw biogas produced per m³ reactor volume per day. In general, further increases in biogas yields can be achieved through better optimisation of the digestion process through increasing the conversion rate, but also through improved feedstock mixes and better instrumentation, control and automation (Cook 2006).

The present growth rate in annual biogas production in Sweden for co-digestion reactors is at least 20% (Cook 2006). Even though the highest potential is expected to be within agriculture (energy crops), biogas production in farm plants is still very low, though there is a growing number of plants. Signs of early maturation of the biogas markets are already visible in Sweden. New players are entering the market and in Bjuv (near Helsingborg), for example, a new plant owned by a pig farmer, E.ON gas and a Danish AD technology company has just

started its operations (Christensson 2006, Linné 2006). This digestion plant did not apply for investment finance from the KLIMP programme.

According to a representative of AGA Gas, the interest of gas distribution companies in the biogas sector is based on the fact that biogas is a locally produced fuel and the development of biogas markets has so far occurred in a regional context. This means that if a certain company gets the local contract for distribution of biogas and purchases of the clean gas, it will have a 'local monopoly', making costs higher for new market entrants. This compensates for the otherwise high and risky investment in a new business area, which is sensitive to changes in government policy (Andersson 2006).

As showed by the example of the Bjuv plant above, energy companies are becoming more involved in the biogas market and aiming to cooperate with farmers. E.ON, for example, has expressed interest in cooperating with farmers in Kristianstad in biogas production. The development of cooperation between farmers and this energy company has been slow so far due to, among other things, the fact that E.ON has not yet been able to confirm what kind of prices they would be willing to pay to the farmers for biogas produced. In addition, the farmers themselves are in the process of evaluating different ways for them to engage in the biogas chain (Christensson 2006).

The contribution of the agricultural sector to the renewable energy market has so far consisted of the cultivation of energy crops. The shift towards cultivation of energy crops has been motivated by the shift in EU agricultural policy since 2003 towards providing higher subsidies for the cultivation of energy crops than for food crops. Recently, farmers and their associations have become more aware of the opportunities that becoming an energy producer would present. However, the high investment costs, lack of technological know-how and the need to form farm cooperatives for energy production to achieve sufficient scale economies are currently acting as a barrier to farmers becoming producers of bioenergy (Christensson 2006, Johansson 2006). However, farmer's associations such as the Federation of Swedish Farmers (LRF) are currently investigating the possibility to overcome these barriers on behalf of individual farmers.

As has been demonstrated above, interest in biogas production is increasing among different players in the market, where varying business models for biogas production can be designed depending on who the potential plant owner is. This increasing interest of various players in biogas production is a clear demonstration of biogas systems starting to reach a certain stage of maturity. This means that the answer to the question asked at the beginning of this chapter: "Will AD be able to succeed on its own right (with less government support) in the markets as a technology, which can contribute to the achievement of multiple environmental objectives?" is yes. However, various factors which are discussed in the following section, will influence the success rate of AD in the near future.

The identified three key measures on behalf of the political subsystem that have influenced this development in the techno-economic subsystem so far have been summarized in Table 4, including their stated purpose and impact on biogas systems development. Electricity certificates have been excluded from this table due to the fact that the desired end-use application of biogas in Sweden is vehicle fuel.

Table 4: Key measures and their impact on biogas systems development in Sweden

Measures taken	Purpose	Impact on biogas systems
LIP and KLIMP environmental subsidies	'Make municipalities the motor of ecological changeover' using as guideline the Swedish environmental quality objectives, with special focus GHG emission reduction since 2002.	Made municipalities think about environment in a strategic way and take action, providing an initial push for the building of the first co-digestion plants with commercial aims (sell biogas instead of using it internally and flaring the rest off). Note: LIP and KLIMP grants have also facilitated the development of other systems infrastructure (purchase of buses) than production plants.
Green tax reform	Tax environmental 'bads' while reducing income taxation with an equivalent amount.	Has made biogas cost-competitive in comparison to other fuels in the market.
Other supply and demand side measures in the transport sector	Support transition towards more sustainable transport systems, using public sector procurement for demand creation and setting legal requirements for the provision of distribution infrastructure.	Creation of demand for biogas, and infrastructure development for its distribution (complemented to a certain extent by investment subsidies).

As can be seen from Table 4 none of the measures taken on behalf of the government have directly addressed anaerobic digestion. Rather, these measures have aimed to improve the environmental performance of municipalities, and to promote the use of renewable fuels especially in the transport sector. These political actions have allowed anaerobic digestion as a potentially environmentally superior technology to succeed alongside already relatively well established technological counterparts such as incineration and ethanol production from wheat.

To summarise, environmentally motivated measures such as the LIP and KLIMP environmental investment subsidies as well as the green tax reform from 2001 onwards have been the key actions taken on behalf of the political subsystem, which have contributed to the utilization and widening of the window of opportunity in the techno-economic subsystem from the late 1990s to 2006. The widening of the window of opportunity can be demonstrated by the fact that the market penetration of biogas is increasing and more actors are interested in entering the market, even without the provision of investment finance, as long as government fiscal policy or the increase in the price of fossil fuels (based on either higher extraction or emissions abatement costs) allow producer to maintain the price of biogas sufficiently high, allowing them to get a good return on investment.

3.1.4 Future considerations

It will be very interesting to follow developments in the Swedish biogas sector, especially the evolving role of farmers in the biogas production chain. The fact that they produce the largest amount of raw materials for digestion (manure, crop residues and energyc crops) and are the end-customers for digestate speaks in favour of farmers themselves engaging in biogas production. According to Christensson (2006) interest in digestate, a certificate system which was introduced by the Swedish Association of Waste Waste Management in 2004, might

increase in the future due to declining soil fertility resulting from monocultures. Increasing energy prices leading to higher production costs and higher price for chemical fertilisers might additionally improve the competitiveness of digestate in comparison to chemical fertilisers. The willingness to pay for digestate in organic farming is potentially higher, where a variety of techniques such as crop-rotation need to be used to substitute chemical fertilisers with organic fertiliser (Christensson 2006).

In the future, agricultural policies might turn out to play a much more decisive role in the development of biogas systems. This is due to the fact that the highest biogas potential exists in the cultivation of energy crops for digestion, an area where AD will compete for raw materials (or availability of land area for cultivation of specific crops) not only with the already commercialized technologies but also with new technologies such as gasification, the commercialization of which can be expected to happen in the near future. In the future, production of biogas could even be complemented by the gasification of biomass to produce synthetic natural gas. In fact, the same companies that are interested in biogas, such as the afore-mentioned E.ON, are also engaged in making gasification commercial technology.

Biogas systems are currently a distributed energy systems, owned and operated by regional actors. Lilliehöök from Svensk Biogas (2006) believes that one of the key future challenges is the development of biogas distribution systems. He states that reaching an annual biogas production of 10 TWh and more means that biogas would need to be distributed through longer distances due to the fact that some regions will have high biogas demand and others high supply potential, and distribution is the means of matching the supply and demand. The future will show if the total market for methane gas will grow to such an extent that it will be interesting for the different actors in the market to engage in further development of biogas distribution infrastructure.

3.2 Finland

During the 1960s and 1970s AD was implemented in a handful of waste water treatment plants (WWTP) for the treatment of sewage sludge. During the 1980s eleven new sewage sludge digestion plants were built in WWTP, including two plants owned by industrial actors. During the early 1990s AD spread to the municipal solid waste management sector with the building of a plant in Vaasa, which was followed by the building of four small scale plants in the agricultural sector during the late 1990s. It should be pointed out at this stage that the development of AD as a technology for producing renewable energy for *market purposes* (not only to cover own energy demands, flaring the rest off) still has not started in Finland. Those individual actors in the techno-economic subsystem, who have implemented AD solutions, are using the energy produced mainly for internal purposes in their own facilities.

3.2.1 1960s to 1970s: AD develops as a method for treating liquid waste

The first anaerobic digestion plants in Finland were implemented in the waste water treatment sector where anaerobic digestion of sewage sludge was introduced during the early 1960s (Tampere Rahola) and 1970s (Riihimäki 1974, Lahti Kariniemi 1976 and Mariehamn 1979) (Leinonen & Kuittinen 1999). These waste water treatment plants (WWTP) followed the example of the Finnish capital, Helsinki, where the first anaerobic digestion facility for sewage sludge had been built as early as 1932 (Lundström 2006). The initial motivation for building sewage sludge digesters in the Finnish WWTPs in most cases appears to have been the possibility to reduce sludge volumes up until the 1980s when biogas utilization rates were

improved (Jokela 2006). An exception to this could be Helsinki, where the long experience from AD since 1932 might have allowed them to understand better the potential of producing energy for internal use in the plant using AD (Lunström 2006). Despite AD having been implemented in a handful of WWTPs during the 1960s and 1970s, the main application for sewage sludge during those decades was still landfill. It was only during the end of the 1970s and the beginning of the 1980s that more pressure was put on the WWTP with regard to treatment and end-disposal of sewage sludge (Lundström 2006).

Due to the small population density in Finland (currently 16 inhabitants per km²) finding new disposal sites for the increasing amounts of waste, caused by the beginning of the consumer goods era at the turn of the 1960s, was easier than in countries with higher population density such as Sweden (currently 52 inhabitants per km²). During the 1960s and 1970s landfill of waste was the only real waste treatment alternative in Finland, even though the environmental problems related to it started to be identified during the 1970s (smell, leachate, rodents).

Contrary to the Swedish model, incineration as a waste treatment alternative did not experience strong growth during the 1960s and 1970s. This is partially due to the fact that the reputation of mass incineration in Finland was damaged by the Kyläsaari plant, built in Helsinki in 1961. This incineration plant was closed down in 1983 due to inefficient combustion process with a resulting incineration product that had not been fully burned (dust and heavy metal emissions, smell and hygienic aspects considered a problem) (Lilja 2006). The only currently operational mass incinerator was built in the city of Turku in 1975. This plant, which was re-fitted in 1995, treats today 50,000 tonnes of municipal solid waste annually, while producing 110GWh of energy that covers 7% of the total sales of district heat in the area (Turun kaupunki 2002).

In the agricultural sector, anaerobic digestion was considered an option for the treatment of manure as early as the 1970s. A Finnish AD technology called Mabi was even developed. However, this technology did not function properly (not enough power, small gas storage tanks), giving no clear incentive for the implementation of AD in the farms (Kalmari 2006). The demand for AD in those days was low because no legal demands were set for the treatment of agricultural waste. The same was the case from the point of view of nutrient recycling: the use of chemical fertilizers and application of manure on cultivated land was not regulated by law. It should also be pointed out that, prior to the energy crises of 1973 and 1979 cheap fossil energy was available in abundance not giving any specific incentives for finding new energy sources (Väisänen 2006).

As a final remark, it should be noted that the energy crises led to the further development of renewable energy technology in Finland, but the efforts were mostly concentrated on the development of technologies suitable for wood biomass, which is widely available in Finland.

No socio-cultural window of opportunity can be identified for anaerobic digestion as an environmental technology during the 1960s and 1970s. The developments that took place in a handful of waste water treatment plants were not the result of specific environmental concerns but rather a small 'niche' market (treatment of sewage sludge to reduce volumes) where anaerobic digestion could compete in its own right. An interesting observation though, is that there were attempts from actors in the techno-economic system to develop AD for farm purposes. These efforts did not materialize due to the fact that the environmental and economic demand for this technology in the agricultural sector did not exist at the time.

3.2.2 1980-1995: Composting main competitor to AD

In the waste water sector, the early 'niche' market for AD, eleven new sewage sludge digestion plants were built during the 1980s including two plants owned by industrial actors. The number of plants in the waste water treatment sector has since remained almost the same, with the exception of two more plants in the municipal and another two in the industrial sector. This is a sign of a saturation of the market need for AD technology in the waste water sector. Therefore, it is interesting to observe if any windows of opportunity for AD (based on environmentally or otherwise motivated arguments) can be identified during the 1980s, which could have led to the further implementation of this technology in the solid waste management or energy supply sectors.

According to Lilja (2006), the central goal of the Finnish waste policy during the 1980s and 1990s was to replace small municipal landfills with regional landfills through municipal cooperation. This development was initially driven by the tightening environmental regulations as well as demands for better monitoring of landfill activities. Both of these demands resulted in municipalities seeking cooperation in order to keep their operational costs low. It was also during the 1980s that biogas was first discovered in the solid waste management sector, as an environmental (methane emissions) and security (explosion) problem in landfills. Consequently, the first landfill gas collection system was implemented in 1989 in the Vuosaari landfill in Helsinki (Väisänen 2006). It should be pointed out that the implementation of landfill gas collection systems is in no way related to the development of AD technology but just an end-of-pipe method for dealing with methane emissions from landfills.

It was also during the the 1980s that the two main Finnish waste treatment alternatives (if recycling technologies for glass, paper and metals are not considered) for the diversion of waste away from landfill were developed, namely composting and co-incineration of solid recovered fuels (SRF – source separated and shredded streams of paper, wood and plastics mainly from industry).

During the 1980s, co-incineration of SRF was first implemented in industrial CHP units based on fluidized bed combustion technology, which was originally developed for burning bark and wet sawdust (Hietanen 2006). It is the Finnish alternative to Swedish mass incineration as the first choice waste-to-energy technology, due to the fact that its electric conversion efficiency is superior to that of mass incineration (Hietanen 2006). The electric conversion efficiency is an important consideration in Finland, which makes very efficient use of CHP production corresponding to 30% of the total electricity consumption, the highest figure in the world¹⁰ (Tarjanne & Kivistö 2006). An initial push for the implementation of co-firing technologies might have also been provided by the 1970s oil crises. Co-incineration is an interesting alternative from the point of view of AD development since it does not compete for raw materials with AD like mass incineration does. This implies that there would be a market demand for AD. However, in the Finnish case the success of composting technology was to become considered as one of the barriers to further implementation of AD in the waste management sector.

Composting technology was developed during the 1980s, and applied to treatment of sewage sludge (landfill of sewage sludge became problematic due to its high water content causing a shift to composting). That AD did not become the technology of choice for the treatment of sewage sludge is due to the fact that certain WWTP were, and still are, relatively small units for

¹⁰ In Sweden this figure is 8.7% (Tarjanne & Kivistö 2006)

which an investment in an AD facility can present significant costs. Another reason is that the perceived benefits of AD are not very significant. It makes better sense for some waste water treatment plants to use calcium treatment to stabilize the sludge, which can then be applied in productive land. This treatment is considered a good option because Finnish soil is acid and application of calcium treated sludge can reduce soil acidity (Lundström 2006).

During the late 1980s composting also started to be applied to biodegradable waste from households. This attempt to divert biodegradable household waste away from landfill was not pushed by the government but rather by municipalities, who wanted to reduce the amount of gulls and rats in landfill areas and reduce environmental problems related to landfill. The composting boom of the 1980s slowed down during the 1990s due to poorer process performance than expected and concerns of health officials over the hygienic quality of the compost (Lilja 2006). The Ämmässuo composting facility, the case for which has been described below, is a good example of a facility where the initial process performance has not fulfilled the expectations.

The case of Ämmässuo composting facility in Espoo

YTV (the regional public waste management company for Helsinki metropolitan area) built a composting facility in close proximity to the Ämmässuo landfill in Espoo in 1997. This facility was designed to treat 30,000 tonnes of source separated biowaste annually. Due to problems with process performance (e.g. compost did not mature as fast as intended) the real capacity of this composting plant is in the range of 20,000 tonnes annually, with a total investment cost of approximately 5.14 million EUR for YTV (adjustments to the plant included). YTV is now in the process of building a new composting plant, the total cost of which will be EUR 23 million with a total annual treatment capacity for 49,000 tonnes of source separated biowaste. When the new plant comes into operation the old composting plant will be used as an after-composting storage facility. The total investment costs for the old and the new composting plant in Ämmässuo together are approximately EUR 28 million (Lipasanen 2006). According to a representative of MK Protech, a company specialized in delivery of turn-key solutions for anaerobic digestion, a digestion plant for the 50,000 tonnes of biowaste that the facility composts annually would have cost 15.5 million euros (including an additional EUR 2 million thermal digestate dewatering unit) (Kutinlahti 2006).

Due to the absence of mass incineration in Finland, composting technology has, up until recently, been the main competitor to AD in the solid waste management sector.¹¹ This statement is confirmed by Lilja, who states that composting has been the preferred treatment option for biodegradable waste, and it has also been considered the “green alternative to incineration” by many municipal decision makers (Lilja 2006). The initial success of composting can also be partially contributed to the fact that influential Finnish companies such as VAPO (State fuel office) were involved in the development and commercialization of this technology during the 1980s. On the other hand, other big companies such as Outokumpu and Neste had showed initial interest in the development of AD technology.

The most significant event in terms of AD during the period from 1980-1995 was that, in 1990, the first Finnish co-digestion plant started operations in Vaasa.¹² This plant experienced

¹¹ Co-incineration is not considered to compete with AD because it is not well suited for the burning of biowaste. The second generation co-incineration technology, gasification, can however deal with up to 35% moisture content in the gasifier feedstock.

¹² This plant was designed by a company called DN Bioprocessing (of which 50% was owned by Neste and 50% by an investment company). The waste pre-treatment unit for this plant was designed and delivered by Outokumpu.

serious problems in its start-phase, a fact which soon became well-known among different actors in the solid waste management sector. Even though the plant is still in operation and now functioning properly, its problems during the relatively long start up period damaged the reputation of AD in Finland.

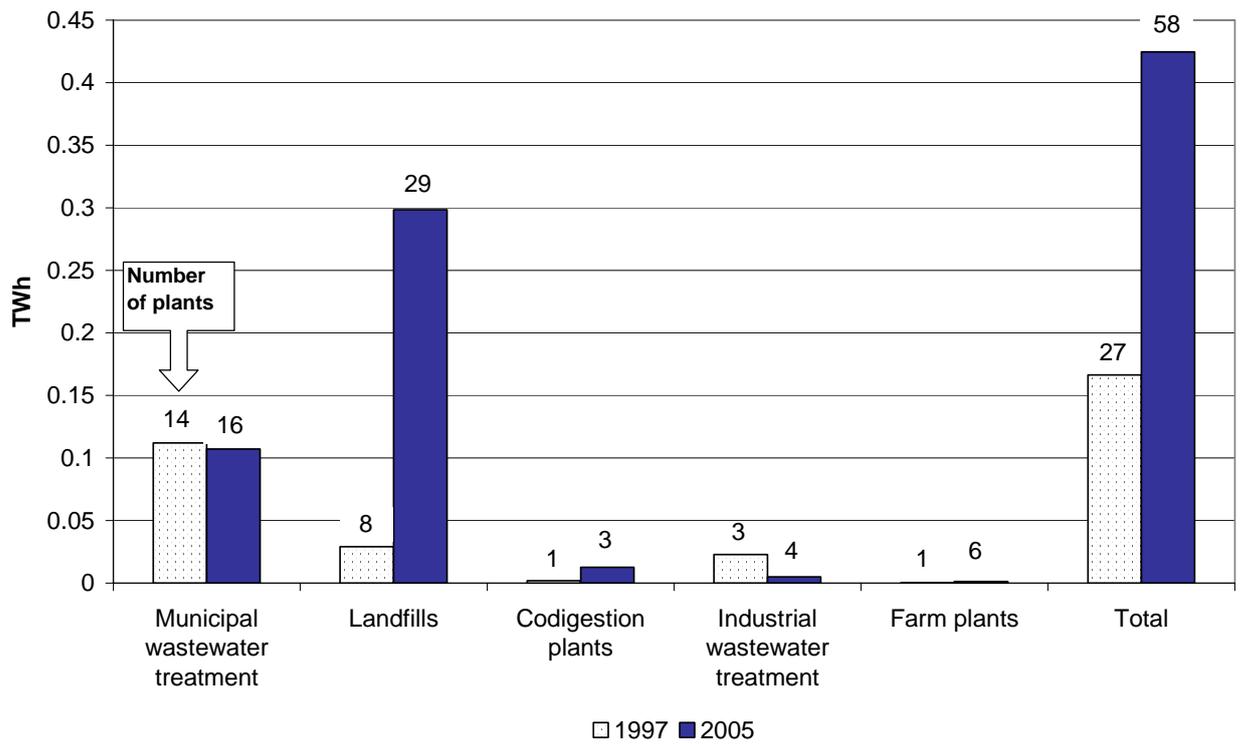
During the 1980s, the discovery of problems related to landfill of biodegradable waste contributed to the opening of a window of opportunity for AD in the socio-cultural subsystem. This window of opportunity was, however, utilized to the benefit of composting due to the perceived high investment costs of AD. During the late 1980s and early 1990s a window of opportunity for AD can also be observed in the techno-economic subsystem. The main reason for this window of opportunity was that AD became for the first time considered a technology that could be used for energy production purposes (WWTPs started making better use of biogas to produce energy for internal consumption in the plant). Consequently, the first co-digestion plant was built in Vaasa in 1990. However, due to the poor performance of this plant (technical consideration), and lack of legal or economic incentives supportive towards AD (government influence on the techno-economic subsystem) this window of opportunity was not utilized to the benefit of AD. The main response of the Finnish political subsystem to the increasing scientific evidence over environmental problems related to landfill (message from the socio-cultural system) was to concentrate landfill in larger units to monitor their activities better. The implementation of new waste management solutions was based on the proactiveness of the actors in the techno-economic subsystem. That is to say, the only societal subsystem where no window of opportunity for AD can be observed during the time period 1980-1995 is the political subsystem.

3.2.3 1995-2006: EU influences Finnish environmental policy

In the Finnish case, no window of opportunity for AD in the political subsystem can be identified prior to 1995. This is an interesting observation if linked with the fact that biogas production *using anaerobic digestion technology* actually decreased between 1997 and 2005 (see Figure 14). The only reason why total production of biogas seems to have increased significantly (in percentual terms) during approximately the past ten years is that the collection and utilization¹³ of landfill gas, mandated by the EC landfill directive, has increased. Based on these findings, it is relevant to assess the Finnish policies in order to first determine (i) whether a political window of opportunity for AD technology can be identified during the past ten years, and if so, then proceed to analyse (ii) whether actions taken by the actors in the political subsystem have enabled the utilisation of the already identified window of opportunity in the socio-economic subsystem for AD. Conclusions will finally be drawn on the impact of government policies on biogas systems development.

¹³ The overall utilisation rate of produced biogas increased from 48% in 2004 to 65% in 2005 (Kuittinen et al. 2006)

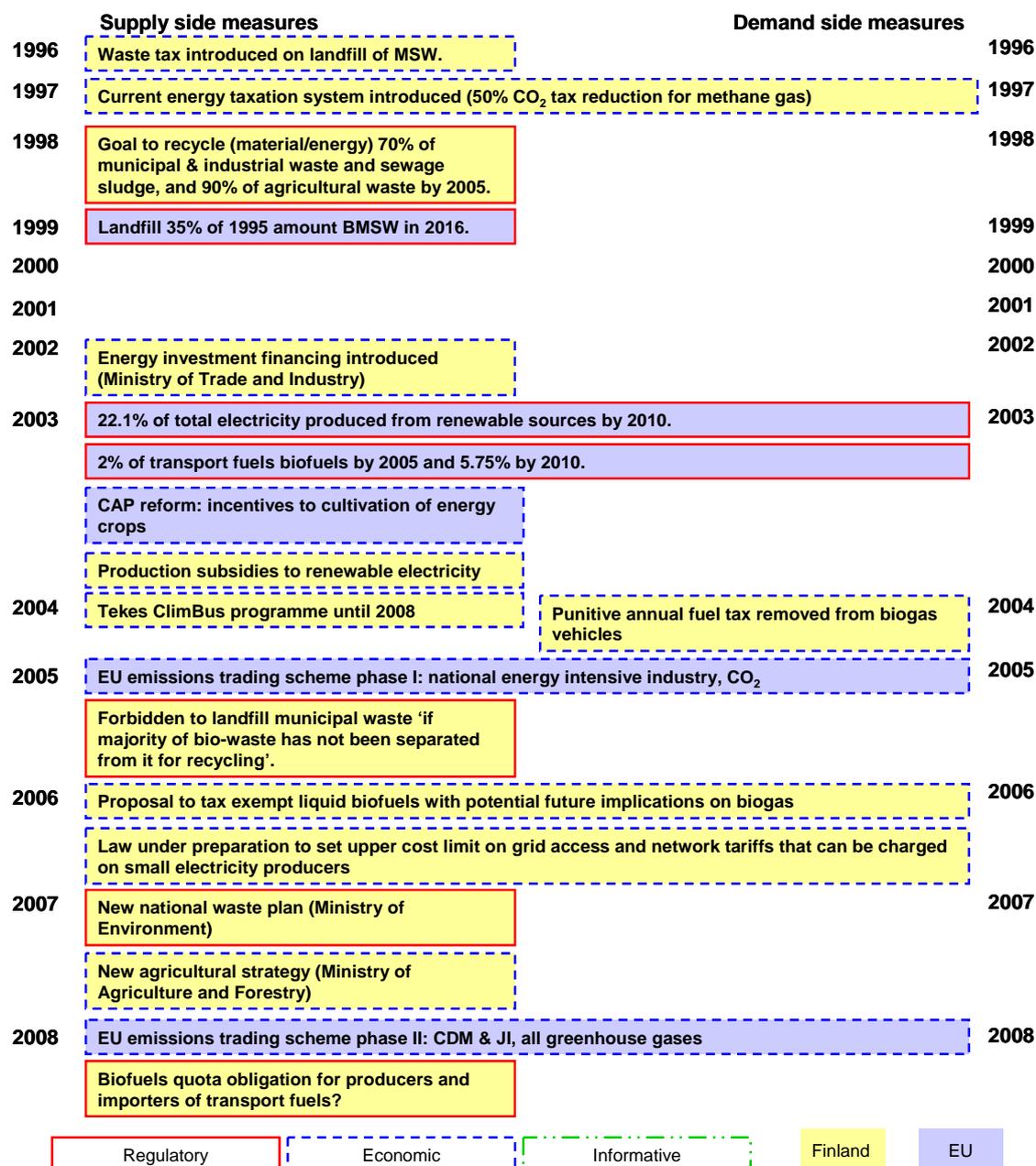
Figure 14: Biogas production and number of facilities in Finland, 1998 to 2004



Source: Leinonen & Kuittinen 2000, Kuittinen et al. 2005

The access of Finland to the EU meant that Finnish governmental policies would, from 1995 onwards, have to be in line with those of the EU. The government policies, which since 1995 have influenced the development of biogas production, have been summarised in Figure 12, differentiating between: year of introduction of the policy instrument; policy owner (EU, Sweden); type of policy instrument used (regulatory, economic, informative); and whether the instrument is geared towards creating more supply or demand for biogas (demand side measures, supply side measures).

Figure 15: Finnish political subsystem - policies affecting demand and supply of biogas since Finland became EU member in 1995



Landfill of waste was still the dominating waste treatment method in Finland during the accession of Finland to the EU, a situation which has remained unchanged to date. According to Lilja (2006), diversion of biodegradable waste away from landfill finally gained wider political support in Finland when the drafting of the EC landfill directive started. This directive from 1999 (Council Directive 1999/31/EC) states that by 2016 member states are restricted to landfilling a maximum of 35% of the total amount by weight of biodegradable municipal solid waste (BMSW) produced in 1995.

Targets for Finnish waste management were reviewed in line with the EU landfill directive in various occasions (Finnish Ministry of the Environment 2002, Finnish Ministry of the Environment 2004). However, the measures taken have either (i) provided only a limited incentive for diversion of waste away from landfill (low level of the waste tax which was introduced in 1996, currently standing at 30EUR per tonne) or (ii) been difficult to monitor

(1998 70% recycling target for municipal waste; 2005 ban on landfill of ‘municipal waste if majority of biowaste has not been separated from it for recycling’). Hietanen (2006) states that the two main barriers to AD in the waste management sector have been the low cost of landfill and the fact that composting was initially considered a cheap investment and a good way of treating waste.

In the Finnish case we can conclude that, to date, no effective measures have apparently been taken to (i) divert waste away from landfill (ii) favour biological treatment over incineration, or (iii) encourage digestion over composting. Being aware that the new national waste plan is due by the end of year 2006, for the time being we need to continue the analysis by looking at other government policies than waste, which could have potentially provided an incentive to increase the production of biogas.

In the Swedish case, environmental policy and its influence on other policy areas was identified as one of the driving forces for the success of AD. Even though environmental issues have a high priority in the Finnish political agenda, they are not usually managed in an integrated manner. This statement can be illustrated by the fact that the “National strategy for reducing landfill of biodegradable waste” from 2004 (Finnish Ministry of Environment 2004), for example, does not take into wider consideration the impacts of improved waste management in other policy areas, such as the reduced climate impact based on replacing fossil fuels with biogas (Finnish Biogas Association 2003).

Climate change was recognised as an environmental problem at international level during the late 1980s. A demonstration of this development was the establishment of the Intergovernmental Panel on Climate Change at the turn of the decade. In Finland, however, the political response to deal with this problem was delayed until talks on emissions trading started, the EU emissions trading system coming into force in 2005. The Finnish target under the EU emissions trading scheme is to keep its average annual GHG emissions during 2008-2012 at the same level as in 1990. The total emissions of greenhouse gases in Finland exceeded this target by 14.5% in 2004 (Statistics Finland 2006b).

While the Finnish government recognises that the domestic energy sector, including development of renewable energy, is one of the key target areas for emissions reductions, it is at the same time also looking to achieve emissions reductions in the most economical way by purchasing emissions reduction credits from abroad through Joint Implementation and the Clean Development Mechanism (Finnish Ministry of Trade and Industry 2005). This is in contrast to the Swedish strategy, which states that emissions reductions should be achieved using domestic measures.

Even though the Finnish argument that it might be cheaper to achieve GHG reductions through projects abroad is true, it does not fully take into account another important factor, the increasing prices of imported energy (fossil fuels and uranium), which is continuously improving the price competitiveness of renewable energy in the market. Information on price developments of these two energy carriers has been included in the box below.

Price development of crude oil and uranium

World uranium prices have been increasing rapidly since their all time low of 7 dollars per pound in December 2000 to 47.50 dollars per pound as of July 2006 (The Ux Consulting Company, 2006). Prices of fossil fuels are also increasing. Price of crude oil increased from around \$20 per barrel in August 2001 to over \$70 per barrel in August 2006 (Energy Information Administration 2006). These higher energy prices are mainly due to the increased costs on the extraction of fossil fuels and uranium from reserves that are more and more difficult to access. These developments in market prices of conventional energy carriers are reflected in the prices of energy for households and industry.

The electricity prices in the EU15 rose by 4.5% for households (all taxes included) and by 15.5% (VAT excluded) for industrial customers from January 2005 to January 2006. During the same period, the price of natural gas increased by 16% for households (all taxes included) and by 33% for industry (VAT excluded). Price developments in individual member states can be quite different though. For example, while the electricity prices for industrial customers increased by approximately 30% in Sweden the prices for Finnish industry went down by 2%. The same figures for household electricity customers were around 6% and 2% respectively (Eurostat 2006a and 2006b). Electricity prices are expected to increase further as the European emissions trading scheme develops (Tarjanne & Kivistö 2006).

As has been demonstrated in the box above, Finnish energy prices have not been subject to as significant upward price developments as Swedish prices. This is due to the fact that, up until today, Finland has been in a privileged position due to the country's historically good relations with Russia, who supplies Finland with cheap energy. However, Finland's good relation with its neighbouring countries is not a guarantee of continued supply of cheap energy in the future. In December 2005, for instance, Sweden limited the supply of electricity to Finland due to internal problems with distribution. Then, in January 2006, Russia also limited energy export to Finland (Tarjanne & Kivistö 2006).

These recent events in the market indicate that the current 70% dependence on imported energy of the total energy consumption (Tarjanne & Kivistö 2006) is a potential threat to the security of energy supply in the future. In addition, Finnish energy prices are expected to keep rising due to the increased extraction costs for conventional fuels and the introduction of the EU emissions trading scheme. Tarjanne & Kivistö (2006) calculate that: with an estimated emissions allowance price of 20 EUR per tonne, and estimated 11 million tonnes of excess GHG emissions annually, not achieving the target set by the EU emissions trading scheme will cost Finland over 200 million EUR annually, and that this will have a direct upward impact on electricity prices.

The above arguments demonstrate that development of renewable domestic energy sources can, in fact, pay off in the long run (instead of being mainly considered as a way of combating climate change). To follow up this argument, it is interesting to see how production of renewable energy (including biogas) is supported in Finland. There are various ways of supporting the development of renewable energy. In the Swedish case, initial investment subsidies, the green tax reform from year 2001 onwards, the green electricity certificates system introduced in 2003, and other supporting measures for making markets more receptive to renewable fuels were considered some of the key driving factors for the development of biogas production.

Investment subsidies

In Finland, it is possible to apply for *investment subsidies* for biogas projects. Energy financing has been coordinated by the Ministry of Trade and Industry since 2002, and focuses on investments that are directly related to a specific energy production technology serving a commercial purpose (Finnish Ministry of Trade and Industry 2005b). For example, AD facilities constructed for waste treatment purposes or projects related to the building of biogas distribution infrastructure do not qualify for these subsidies. In 2005, 86% (28.5 million EUR) of energy finance was spent on renewable energy technology. 70% (19.7 million EUR) of the renewable energy technology finance was directed to technologies making use of forest biomass. Biogas production subsidies totalled 2.5 million EUR.

TeKes, the Finnish funding agency for technology research, has since 2004 run the ClimBus programme (Business Opportunities in Mitigating Climate Change). The aim of this programme, which is to run until 2008 with a total budget of 70 million EUR, is to find and promote technological ways to mitigate climate change, thus creating international business opportunities for Finnish companies. TeKes financing generally concentrates on the research, development and, to a certain extent, demonstration phases of specific technological innovations. This means that the building of AD plants, which is already considered commercial technology, does not qualify for ClimBus finance. So far one of the ClimBus financed projects is related to biogas technology, the project owner being Greenenvironment Oy and their area of focus being the development of new gas pre-treatment and compression technology. (TeKes 2006)

The Finnish Ministry of Agriculture and Forestry is currently in the process of reviewing its subsidies policy for the next strategic period starting from 2007. Reskola (2006) points out that when the current agricultural strategy was developed in Finland at the end of the 1990s the importance of bio-energy was not fully understood. Now this understanding has increased and the production of bio-energy, including biogas, is included in the new strategy, the implementation of which will start in 2007. However, it is not yet clear how much financial support will be given to biogas production and upgrading installations. Kalmari (2006) believes that investment subsidies would be a good way of supporting the building up of Finnish AD plant network in the agricultural sector. This practice would not differ significantly from the current scheme under which it is possible to receive a subsidy that covers 50-60% of the investment costs for the building of a new housing unit for pigs, for example. Kalmari believes that the fundamental question is whether energy production can – from the government viewpoint – be considered agricultural business to the same extent as e.g. meat production. He also believes that environmental subsidies could be another way of supporting AD technology, which brings with it several environmental benefits.

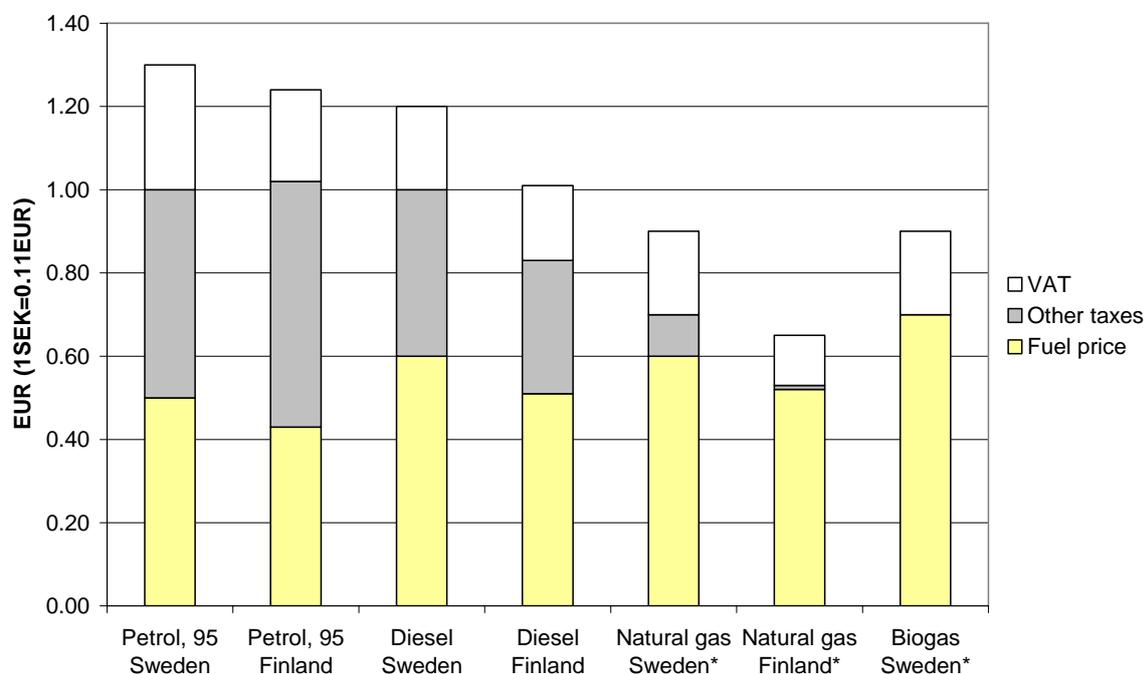
Production incentives

Even though investment subsidies can encourage different actors to enter the biogas market, the long-term profitability of the business depends on how cost-competitive biogas is in comparison to competing products. *Fiscal policy* is one way of influencing the price-competitiveness of different energy products in the market. The final market price of conventional fuels can for instance be increased through taxation, which in turn improves the competitiveness of renewable fuels that are currently more expensive to produce than conventional fuels. We will now look in more detail how biogas as (i) vehicle fuel and (ii) fuel used in electricity production has been supported through government policies.

Biogas for vehicle fuel - A comparison of vehicle fuel prices in Finland does not give the reader any information with regard to the cost competitiveness of biogas as transport fuel. This is due to the fact that there is currently no market for biogas driven vehicles in Finland

(no infrastructure and only a couple of interested customers with a suitable car). However, a comparison of the Finnish vehicle fuel prices with the Swedish prices, as demonstrated in Figure 16, shows that the price of natural gas is much lower in Finland than it is in Sweden. This is due to two reasons. The first reason is that the price for natural gas bought from Russia is cheaper than the Swedish natural gas which comes from Denmark. Secondly, Finnish natural gas benefits from a 50% carbon tax exemption (Tarjanne & Kivistö 2006). Biofuels are not tax exempted in Finland as they are in Sweden. This means that biogas is subject to the same tax as natural gas. Interestingly enough, other biofuels are taxed even higher than biogas. Tax on fossil diesel fuel for instance is 32c/l and on biodiesel 35c/l. In March 2006, a proposal to change the current law on liquid vehicle fuels so that it would give them an excise duty exemption, now signed by 143 MPs, was handed over to the Finnish parliament (LA 9/2006). This proposal does not concern biogas but might lead to further negotiations over tax-exempting biogas if the proposal goes through.

Figure 16: Comparison of vehicle fuel price composition in Finland (March 2006) and Sweden (June 2006)



Source: *Fordonsgas 2006, Swedish Petroleum Institute 2006, Gasum 2006, Tilastokeskus 2006a*

The EU transport biofuels directive (Commission Directive 2003/30/EC) demands that 5.75% of transport fuels must be biofuels by 2010. The Finnish Biofuels Committee, which published its findings regarding the implementation of the EU transport biofuels directive in Finland in May 2006, considered that an economically realistic target for Finland would be a 3% biofuels share by 2010. It also recommends that a quota obligation would be the best way to achieve this target, based on the argument that market players can find the most economical way to fulfil this obligation including, for instance, import of Brazilian ethanol (Finnish Ministry of Trade and Industry 2006). The targets set in the transport biofuels directive are considered ambitious by most EU member states.

Biogas for electricity - The EU also regulates the production of green electricity through a EU-wide 22.1% target – and a specific Finnish 31.5% target – for electricity produced from renewable energy sources by 2010 (Commission Directive (2001/77/EC). The annual production of green electricity in Finland equalled 28% in 2004 (Tarjanne & Kivistö 2006).

Finland has been taxing electricity consumption instead of electricity production since 1997. The practical implication of this approach is that the fuels used for electricity production are not taxed, eliminating the potential fiscal incentives for using renewable fuels in electricity production. Production of renewable electricity has, however, since 2003 been supported through *production subsidies*, which are paid to electricity produced from: wind energy and forestry residues (0.69c/kWh); hydro power, wood biomass, biogas, exothermic heat of chemical reactions and waste gases of metallurgical processes (0.42c/kWh); as well as co-incineration / co-gasification of SRF (0.25c/kWh) (Tarjanne & Kivistö 2006).

One effective barrier for small producers to engage in the production of green electricity so far, has been the high fees incurred with selling electricity to the grid: The current market price of electricity for household customers is approximately 10c/kWh (Statistics Finland 2006a), of which 3.9c goes to the producer, and 3.5c to the grid owner in network tariffs, and the rest being taxes (Tarjanne & Kivistö 2006).¹⁴ The initial installation fee (for grid access) and the electricity network tariffs, set by the big producers who own the grid, are too high to provide small producers with a financial incentive to engage in the production and sale of green electricity (Kalmari 2006, Kyytsönen 2006). The government is currently preparing a law that would set the upper limit for electricity transfer fee at 0.07c/kWh. In addition, the initial installation fee for access to the grid would be no more than the actual cost of the work carried out. If this law comes into force in its present form it will provide tens to hundreds of small producers with the incentive to sell electricity to the grid (Kyytsönen 2006). It should be pointed out that the law in preparation is motivated by the EU electricity market directive (Council Directive 2003/54/EC) that came into force in 2003, and aims to establish a fully open internal energy market where all consumers are free to choose their suppliers and all suppliers are free to deliver to their customers.

Other measures facilitating market penetration of biogas

In Finland, certain barriers that have been slowing down sales of biogas have been removed during the past ten years. One barrier that was considered an unfair barrier to the sales of biogas driven vehicles was removed in 2004. It was then decided that methane driven cars would be exempted from the punitive fuel tax applied to all other motor vehicles using fuels taxed less heavily than petrol, e.g. diesel driven vehicles. This tax was 6.7c per day per 100kg of car weight. I.e. a car that would have a weight of 1500 kg would pay an annual tax of 360 EUR (0.067*15*360). (Ministry of Trade and Industry 2005c) However, up until 2006, the 'tax relief' given to biogas vehicles was conditional in the sense that it was only granted to biogas vehicles, which would fulfil the next international emissions standards coming into force (the prediction of which in practice is difficult).

Impact of government policies on diffusion of AD

As has been demonstrated in this chapter, the political subsystem has, after the entrance of Finland to the EU in 1995, implemented a number of measures that aim to provide incentives for the production of renewable energy. These measures include: subsidies provided to energy investments with commercial aims since 2002; production subsidies to renewable electricity; and the current measures under preparation to exempt liquid biofuels from taxation and reduce costs of grid use for small electricity producers.

Even though all of these measures can in theory benefit biogas production, in practice they have not led to a significant increase in biogas production (see Figure 14 p.45). However, some positive examples exist in the Finnish market where individual actors themselves have

¹⁴ Price composition of electricity: 39%, transfer price 35%, taxes 26% (Tarjanne & Kivistö 2006).

engaged in biogas production. Table 5 outlines the key political measures taken between 1995 and 2006, the purpose of these measures and the impact of these measures on biogas systems. The aim of the table is to demonstrate to the reader why the measures taken by the government have not been more effective in supporting biogas systems development (only 2 more co-digestion plants built since 1997).

Table 5: Key measures and their impact on biogas systems development in Finland

Measures taken	Purpose	Impact on biogas systems
Energy finance (investment subsidy)	Promote more environmentally friendly energy production by providing investment finance for technologies that are used to produce renewable energy. Projects need to have a commercial aim.	Total finance received for biogas production related investments in 2005 was limited to 2.5 million EUR. Only those proposals qualified, which have a commercial aim and focus is on energy production. I.e. Biogas projects with waste related or environmental goals do not qualify. Finance is not provided for the building of biogas related infrastructure.
ClimBus finance (investment subsidy)	Find and promote technological ways to mitigate climate change hereby creating international business opportunities for Finnish companies.	Only one biogas related project has received finance so far. Finance is not provided for market launch of already commercialized technologies but R, D&D of new technologies. No impact on biogas systems development in Finland.
Energy taxation	Fiscal purpose, renewables not tax exempted.	Biogas and natural gas treated the same in taxation (50% exemption from CO ₂ tax), no added incentive for biogas production for transport fuel purposes.
Renewable electricity production subsidies	Compensate for higher production costs in comparison to fossil fuels. Give incentives to produce renewable electricity.	Limited incentive to engage in production of biogas based electricity due to the combined effect of potentially low investment subsidy (0.42c/kWh) and high cost of grid access and usage for small producers.
Punitive fuel tax removed from biogas vehicles.	Remove an unfair tax applied on an annual basis to owners of biogas vehicles.	Removed a barrier to purchase of biogas driven vehicles but does not provide any added incentives for their purchase.

As demonstrated in Table 5, some measures have been recently introduced that could provide added incentives for the development of biogas systems in Finland. In practice, however, both investment subsidies schemes for example can only provide limited support to biogas due to the restrictions that are applied to the scope of the projects. The only measure that has been taken to promote the production of renewable energy is the subsidies paid to production of green electricity. However, perhaps due to the low level of investment subsidy, or more likely, the high price that grid owners charge for access to the grid, biogas based electricity production has not been considered profitable business so far. On the other hand, some measures favourable to biogas are under preparation in the Finnish parliament such as the

planned upper limits on prices that grid owners can charge from small producers, or the quota obligation that is planned for renewable transport fuels for 2008.

It can be concluded that during the past few years a window of opportunity for biogas has opened in the Finnish political system. This window of opportunity is largely based on the country's international commitments (EU renewable energy targets, demands for free market access to all producers, and EU emissions trading scheme) rather than the proactiveness of the Finnish political actors with regard to, for instance, enforcing better waste management practices, or reducing Finland's climate impact through domestic measures (as opposed to the use of JI and CDM). The identified window of opportunity in the political subsystem has not yet been utilized to the benefit of AD, which is demonstrated by the fact that government policies have not facilitated any significant increases in the production of biogas (not counting collection of landfill gas due to the fact that it is as an end-of-pipe technology that cannot be compared with AD).

3.2.4 Future considerations

The future of AD in Finland remains uncertain. The application of biogas as vehicle fuel seems unlikely due to the fact that the government is not interested in investing in expensive distribution infrastructure for gaseous renewable fuels. This does not exclude the possibility of using biogas for stationary fleet such as buses, taxis, and heavy-duty vehicles, for which refuelling can be concentrated in one or two stations. The city of Jyväskylä, for example, has investigated this alternative in detail (Kutinlahti 2006).

What is an interesting feature of the Finnish systems is that composting, despite its poor performance, has until recently played an important role as a competing alternative against AD. This reflects the generally somewhat reactionary approach of the waste management companies towards new waste treatment technologies: approximately 90% of the recycling activities are carried out by private waste management companies. The role of the waste management companies with regard to AD remains to be solved. Taking into consideration the poor process performance of composting and its high operational costs in Finnish conditions it is possible that interest in AD will increase in the future, unless a new superior technology is considered a better alternative than AD. The new National Waste Plan, which is due to be completed by the end of this year, is expected to provide some recommendations as to preferred treatment methods for biodegradable waste. While waste management companies remain passive, the only sector where interest in AD seems to be on the rise is the agricultural sector.

The fact that farmers produce the largest amount of raw materials for digestion (manure, crop residues and energy crops) and are the end-customers for digestate speaks in favour of farmers themselves engaging in biogas production, especially in the Finnish situation where application of compost and digestate on arable land is considered problematic: If farmers themselves were engaged in the production of digestate they would be more confident in its quality. The ownership of the agricultural sector would seem natural considering that the environmental benefits of AD are largest in farms (recycling of nutrients and soil organic matter, reduced eutrophication potential, improved animal health when digested manure is applied on pasture land). The economic benefits of farmers themselves engaging in energy and fertilizer production can only increase in the future due to the increasing energy prices (impact on fertilizer prices) and likely reducing soil fertility due to intensive farming practices.

As mentioned previously, the Finnish Ministry of Agriculture and Forestry is currently in the process of defining a new strategy that will be applied from 2007 onwards (Reskola 2006).

This strategy will define the conditions under which farms can receive finance for the building of AD plants, and adjoining infrastructure. Investment subsidies or the building of AD plants in the agricultural sector could take various forms such as (i) subsidising investments in new business areas (subsidise shift from food to energy production), (ii) subsidies for the introduction of technology that improves the environmental performance of farming (reduced nutrient leaching, reduced eutrophication of aquatic systems, reduced climate impact, improved soil fertility) or even (iii) subsidies to make a shift from conventional to organic farming, where AD can be used to produce organic fertiliser and soil improver.

Long-term success of AD plants in agricultural or any other sector is not only dependent on the initial investment subsidies but also on the end-price of digestion products in comparison to competition, and the availability of infrastructure for biogas distribution. Due to the high investment costs related to biogas, some form of partnership between different actors in the market is likely to be formed: either as farmers cooperatives, between farmers and energy companies, or possibly even the food industry, which has until now contented itself with following the developments in the biogas market without taking any further action.

As stated before, the attractiveness of anaerobic digestion is based on the possibility to obtain multiple environmental objectives related to waste management and nutrient recycling, while producing relatively small amounts of energy per installation. However, this energy production can be significant from a regional perspective. Väisänen estimates the Finnish biogas potential within 5-10 years (not counting dedicated energy crops) to be 1-1.5 TWh annually. He states that 10 big plants could be built within the agricultural sector (including food industry waste), which would supply some 0.15 TWh annually. Achieving this target requires government support to regional actors and would act as an excellent way of starting up the building of Finnish biogas systems in an economically justified fashion.

4 Discussion and analysis

The aim of this chapter is to draw conclusions on the two country case studies concerning key factors that have contributed to the development of biogas systems in both countries from 1960 to date. The key purpose will be to demonstrate when the so-called windows of opportunity for AD technology appeared in three societal subsystems: the socio-cultural, political and techno-economic and what factors contributed to these windows of opportunity being utilised or not being utilised to the benefit of AD technology. It should be emphasised that at this stage the emphasis is on the discovery of AD as a technology that can be used for the production of renewable energy. This analysis is used to answer Research Question 1: What factors have contributed to biogas production developing faster in Sweden than in Finland?

Definition of terms used in the analytical framework model

A window of opportunity presents a specific point in time when the possibilities for environmental innovation to succeed are higher than otherwise due to changes in one of the three societal sub-systems (described below).

Socio-cultural subsystem = Scientific evidence on environmental impacts of specific technologies combined with citizen concern over these issues. Puts pressure on the political subsystem to take action.

Political subsystem = Prioritises different environmental issues based on the feedback from socio-cultural and techno-economic subsystems. Takes action and influences markets to develop in a desired direction through regulation and economic incentives.

Techno-economic subsystem = Actors in the market who make their decisions to implement specific technological solutions (AD), based on an assessment of their own perceived costs and benefits related to the investment.

Definitions based on: Sartorius & Zundel (2005)

Figure 17 concludes the Swedish case and Figure 18 the Finnish case, by (i) illustrating when windows of opportunity opened in the three societal subsystems for AD and (ii) the various factors that have influenced the political subsystem in taking actions that favour AD. A timeline for the development of two other waste and/or energy technologies will be provided as a basis for comparison. In the Swedish case the competing technologies used in the illustration are mass incineration and biomass combustion, and in the Finnish case composting and biomass combustion. The reason for choosing mass incineration in the Swedish case and composting in the Finnish case is that these are the identified main competing technologies to AD in each country. Biomass combustion was used as an example of another renewable energy supply technology because it is a well established and competitive technology in both countries.

Figure 17: Sartorius and Zundel (2005) analytical framework model applied to Sweden

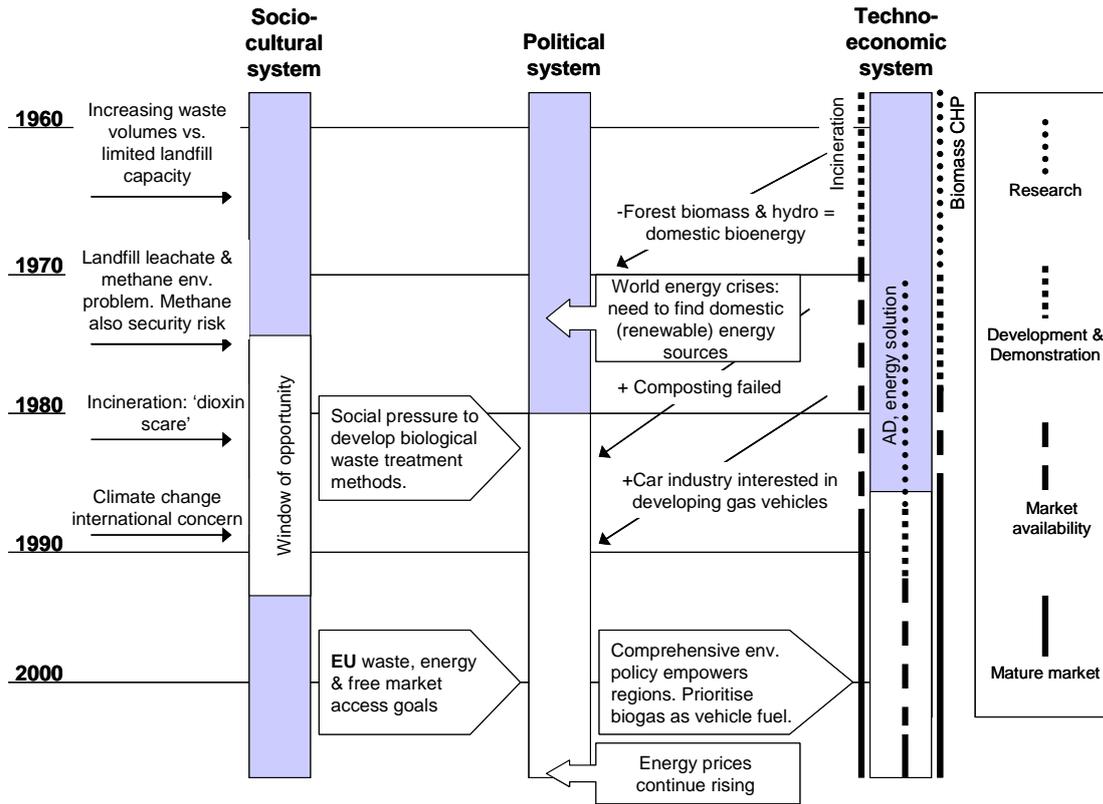
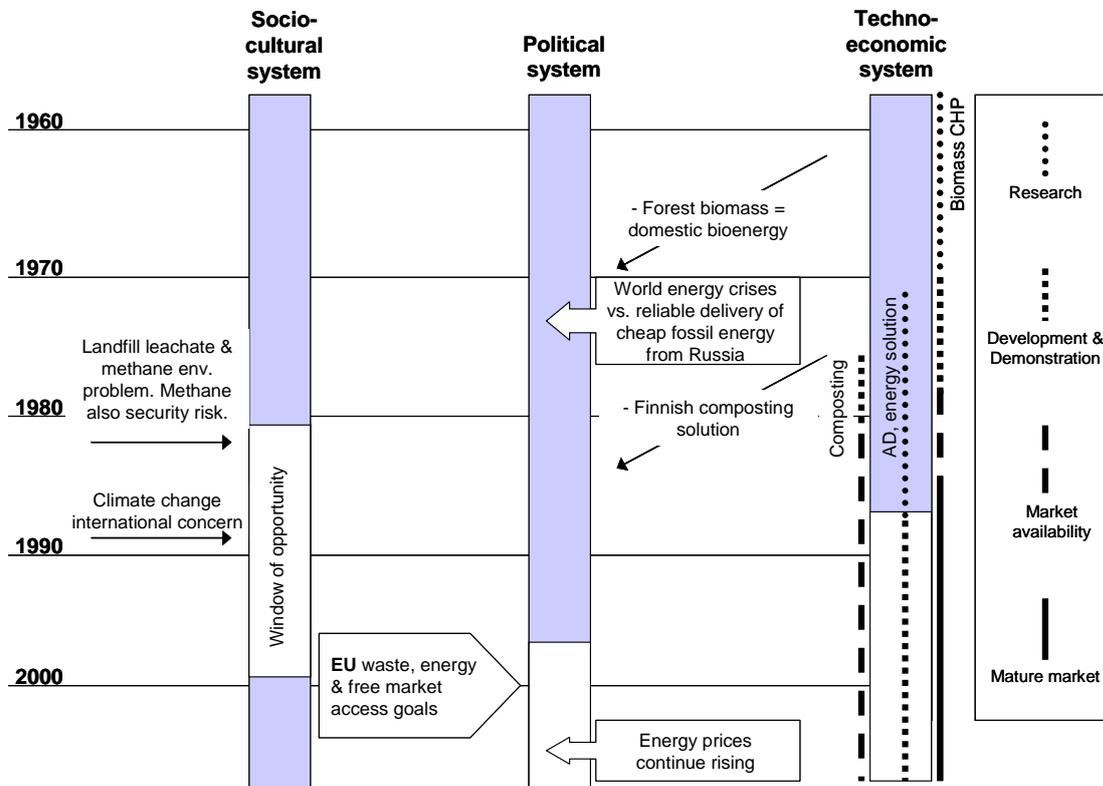


Figure 18: Sartorius & Zundel (2005) analytical framework applied to Finland



The two figures on the previous page demonstrate that there are some key similarities and differences with regard to the (i) influence of the techno-economic subsystem on the political subsystem and (ii) perception on what political actions are needed based on events in international energy markets. For example, when the energy crises of the 1970s occurred both countries prioritised other forms of renewable energy than biogas due to the obvious reason that the energy supply potential of these technologies was higher, and AD had not yet developed as a technology for energy production purposes. However, the fact that Finland was to be provided with a reliable and economical supply of fossil fuels from what is now Russia throughout the following decades might have decreased the Finnish interest in finding other less abundant sources of renewable energy than wood biomass. As was explained in conjunction with the Finnish case study, it is only recently that Finnish energy markets have started to experience increasing energy prices combined with occasional interruptions in delivery from Russia and Sweden.

One factor, which has acted as a barrier to the implementation of AD in the Finnish waste management sector is the existence of composting as a perceived cheaper alternative for the diversion of biodegradable waste away from landfill. In Sweden, early composting attempts were relatively unsuccessful due to the application of mechanical after sorting, which caused a bad quality of the compost end-product. This means that the only potential end-application for the compost produced would be in the landfill area. Landfill capacity in Sweden is more limited than in Finland, which has the practical implication of Swedish waste management companies putting more emphasis on finding productive end-applications for the compost than in Finland. As has been mentioned earlier, effective recycling of nutrients and killing of pathogens through AD makes the end-product of digestion, the digestate, a higher quality soil improver than compost is. Achieving the so called 'full eco-cycle' (compost or digestate applied on arable land) would hence be easier through AD.

An additional push for the development of AD in Sweden was provided by the Swedish automobile industry, which was keen on developing vehicle engine technology suitable for biogas. The cooperation between the Swedish government and car manufacturers culminated in demonstration projects for the use of biogas as vehicle fuel in four selected municipalities during the end of the 1980s and the beginning of the 1990s. In Finland there was no such influential industrial lobby that would have promoted a specific end-use application of biogas. Rather, the government might have been more inclined to promote composting technology, which had been developed by a now former state owned enterprise with a proven track-record in the field of bioenergy and soil conditioner production based on peat.

When climate change became an international concern at the beginning of the 1990s, Swedish scientific circles, having engaged in climate research since the end of the 19th century, were well informed on the causes and potential impacts of climate change. The influence of the Swedish scientific community is probably one of the driving forces behind the early integration of climate issues in the Swedish political agenda. A more environmentally oriented government policy developed throughout the 1990s, with the gradual introduction of environmentally motivated taxes and the development of a set of comprehensive environmental quality objectives, the fulfilment and monitoring of which was to be a shared responsibility between different government agencies. Development of biogas infrastructure continued with other municipalities following the example set by the four pilot municipalities. Government support for environmentally motivated projects, with special focus on curbing climate change from 2002 onwards, was continued through the LIP and KLIMP investment programmes starting from 1998.

In Finland, climate change was given higher priority in the government agenda when the talks on the introduction of the EU emissions trading scheme started (economic motivation), more likely from the year 2000 onwards. The Finnish approach differs from the Swedish approach in the sense that emphasis is put on achieving emissions reductions in the most economical way. This would imply making use of the Joint Implementation and Clean Development Mechanism when they are included in the EU emissions trading scheme from 2008 onwards. Sweden, on the contrary, has not only set itself a stricter emissions reduction target than that officially defined for the country, but it has also been stated in the Swedish Climate Strategy that emissions reductions must be achieved with domestic measures without making use of the flexible mechanisms (CDM and JI). The Swedish climate policy has, hence, been more favourable to the development of domestic biogas related infrastructure – biogas production and consumption being considered an efficient means by the Swedish municipalities to reduce reductions of greenhouse gases at regional level (many of the KLIMP applications have proposed biogas related projects).

One final factor, which has facilitated faster development of biogas systems in Sweden, is that government support is available not only for the building of the digester, as is the case in Finland when applying for Energy Financing, but also for the adjoining infrastructure. This has helped local actors in overcoming the path-dependence effect, the fact that existing systems for distribution and consumption are more supportive towards liquid fuels than gaseous fuels. This is the ‘chicken and egg’ syndrome of biogas in the Finnish context: in order to make use of biogas, investments in infrastructure are needed. Small producers are lacking the finance to do this and big companies do not consider biogas to be a significant enough business area to justify an investment in a totally new type of distribution infrastructure. Use of biogas for CHP purposes could be an option for Finland because it does not require significant changes in the existing systems infrastructure. Additionally, new solutions for small-scale CHP production at farm scale (microturbines) are now enabling efficient small-scale electricity production. However, the high price of grid access is for the time being acting as an effective barrier for small producers to sell green electricity to the grid.

As has been demonstrated in this chapter, there is not one single factor that has contributed to biogas production developing faster in Sweden than in Finland. Rather, this development has resulted from the combined effect of various government policies. The general observation is that biogas systems fit in well in the local agenda. This is due to the fact that biogas systems are considered to be part of distributed energy systems, which create environmental, social and economic benefits at local level. The Swedish government has supported the development of biogas systems at local level through: (i) initial demonstration projects in cooperation with the car industry, followed by (ii) the introduction of an Environmental Policy, which has empowered regions through the provision of finance for projects, which are considered to lead to the best greenhouse gas emission reductions in municipalities. Biogas production has been further supported through (iii) differentiated taxation for fossil and renewable fuels. No such actions have, according to the written and oral sources of information for this research, been taken on behalf of the Finnish government.

5 Recommendations and reflections

It was concluded in the previous chapter that biogas systems development in Sweden has, after an initial push provided through a set of demonstration projects to use biogas as vehicle fuel, benefited from an entire policy framework that was formulated during the 1990s. The key feature of this policy framework is the general concern and even a certain sense of urgency that the Swedish government has articulated with regard to environmental issues. On the basis of the Swedish model, two key reflections on the main shortcomings of the Finnish policy framework can be identified. These reflections are not directly related to biogas but concern the overall deficiencies in the government policies, which are the underlying reason for biogas production not developing faster in Finland. The first reflection concerns the overall environmental policy in Finland, and the second reflection concerns the role of regional actors in achieving environmental goals set at the regional and governmental level.

Finnish environmental policy

Even though environmental goals have been introduced in different policy areas in Finland, no integrated environmental strategy is in place. Integrated environmental strategy refers to an approach that sets the key environmental goals, divides responsibility for their implementation to the most appropriate government agencies and demands annual monitoring to check on progress made and new targets to be set. The benefit of introducing a strategic tool such as the Swedish environmental quality objectives in Finland would be that environmental goals could be effectively introduced in different government policy areas yet the monitoring of progress made would be concentrated on one annually or biannually published document. In Sweden, the environmental quality objectives that were introduced in 1999 have benefited biogas due to the fact that an assessment of the various goals together shows that AD can contribute to the achievement of various environmental goals that are specific for Sweden and agreed upon by the government.

Role of regions in implementing environmental policy

Regional agencies exist in Finland that are specifically responsible for promoting regional growth in chosen business areas. However, regional actors have apparently not been effectively encouraged to approach environmental issues in a more strategic way, in line with national targets. Yet, it is these regional actors who have the best knowledge of the regional conditions and environmental problems that are of specific concern in their region. In Sweden, the government has since 1998 aimed to make municipalities the “motor of ecological changeover”. This aim has been promoted through the provision of investment finance to the best environmental projects in Swedish municipalities. This approach has motivated the municipalities to draft their own environmental and climate strategies, which in turn has led to the (i) implementation of national environmental quality objectives at regional level, (ii) increased understanding of the environmental situation regionally and (iii) better strategic approach on behalf of the municipalities with regard to achieving various environmental targets. In the Swedish case this approach has been beneficial to biogas due to the fact that the positive impacts of biogas systems are easier to understand from a regional perspective than from a national perspective. A similar approach could be considered in Finland due to its positive effect in activating and empowering regional actors in environmental issues.

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Appendix 1 Calculation of biogas potential

SWEDEN

	TWh (Linne & Jönsson)	TWh (Adjusted)	Comment
Sewage sludge	0.97	0.81	Production has remained the same since 1997 (0.81 TWh). Can assume that full potential has been achieved.
Industrial waste (food, waste waters)	0.94	0.94	Modest estimates for pulp and paper industry and private sludge (0.12 TWh). Swedish target to treat 100% of food industry waste biologically. Assumption that 100% of food industry waste is used for digestion is hence in line with the target (0.82 TWh).
Foodwaste from households	0.94	0.94	Based on 70-80% source separation. Ambitious but achievable target that depends on many factors influencing economics of biogas (e.g. energy prices).
Park and garden waste	0.47	0	Excluded because composting is stated to be the preferred biological treatment alternative in Sweden. Finnish estimates also exclude park and garden waste and its exclusion from the Swedish part makes results more comparable.
Manure	2.56	2.56	Estimate based on utilisation of all cow, pig and chicken manure for digestion. In practice, only 75% of cow manure can be used for digestion because cows are out grazing 3 months of the year.
Harvest residues	0.98	0.98	Includes sugarbeet tops, potato refuse, and chaff. Use depends, among other things, on technology availability and price for collection of these raw materials. For sugar beets, for example, technology exists but is not used.
Dedicated energy crops	7.19	7.19	Based on dedicated energy crops being grown on 10% of Swedish agricultural land. The 10% figure is based on demands by EU to leave between 5-10% of agricultural land as set-aside-land, which can be meanwhile used for the growing of energy crops. Potential could be even higher if more land was dedicated to growing crops for digestion.
TOTAL	14.05	13.42	

FINLAND

	TWh (Rintala)	TWh (Adjusted)	
Landfill gas	1.5	0	Excluded due to future targets for diversion of biodegradable waste away from landfill.
Sewage sludge	0.32	0.2	Current production is 0.107 TWh. According to three interviewees - Väisänen (2006), Lundström (2006) and Malkamäki (2006) - further expansion of biogas production in waste water treatment plants is not realistic due to small unit size among other things. Figure increased to 0.2 considering that only 50% of sewage sludge is digested in Finland (Leinonen & Kuittinen 1998) as opposed to some 90% in Sweden.
Industrial waste (food, waste waters)	0.52	0.52	100% (=0.48 TWh) assumed for food industry like in the Swedish estimate. Waste arises as single stream and in large quantities. Easy to collect and treat. Estimate for waste waters is modest at 0.04 TWh. Used as is. $0.48 + 0.04 = 0.52$ TWh
Foodwaste from households	0.36	0.25	Adjusted from 100% to 70% being source separated and digested. Swedish study assumes 70-80%.
Manure	4.3	2	Rintala assumes all to be used like the Swedish study. Note: 4.3 TWh is significantly higher than the Swedish 2.56 TWh estimate for biogas from manure. Since Finland has less farm animals than Sweden, this figure is adjusted to 2 TWh.
Harvest residues	6.8	0.4	Swedish study estimates 0.98 TWh as opposed to the Finnish 6.8 TWh. This difference between the Finnish and Swedish estimate is based on the fact that Linne excluded straw from the biogas potential because of its low biogas yield. In the adjusted figure straw is excluded from the Finnish potential. (Source: Lampinen & Jokinen 2006, p. 39)
Dedicated energy crops	not included	6.6	According to Finnish Ministry of Agriculture and Forestry's Bioenergy scenario, in 2010 energy crops could be cultivated on 510,000 ha of the Finnish field area (Lampinen & Jokinen 2006, p. 41). According to Kalmari (2006), approximate biogas yield per ha of energy crop is 20-40 MWh. Assumed that 10% of Finnish agricultural area (220,000 ha) is used to grow energy crops for biogas with a biogas yield per hectare of 30 MWh.
TOTAL		13.8	9.97

Estimation of the biogas potential in both countries is likely based on average conversion rates of organic substrate into raw biogas (i.e. biogas yield per m³ raw material). There are, however, methods to increase the conversion rate, and thus increase the overall biogas potential. These methods include improved process configuration and reactor technology, and better microbiology (Cook 2006).

With regard to better microbiology of the process, Kutinlahti (2006) states that biogas yield can be increased by 25% through better breaking down of the cell structure in organic waste, while Lehtomäki has discovered that when grass and beetroot are ensiled with additives biogas yields can be increased as much as by 20% (Lehtomäki 2006, p.3).

Appendix 2 Persons interviewed and interest groups they represent

Name	Organisation	Date (2006)	Type of interview	Interviewee represents opinion of:									
				Academia	Government	Municipalities	Waste mgt co's	Farmers	Producers of biogas	Gas distribution and energy companies	Car industry	Consultancy & other specialists services	
SWEDEN													
Andersson Roger	AGA Gas Ab	4 Jul	Phone								X		
Berglund Maria	Lund University (LTH)	27 Jul	Personal	X									
Bramryd Torleif	Lund University, Helsingborg Campus	14 Jun	Personal	X									
Börjesson Pål	Lund University, LTH	8 Sep	Phone	X									
Christensson Kjell	Agellus Miljökonsulter	30 Jun	Personal				X						X
Cook Kristofer	Bioprocess Control Sweden Ab	7 Sep	Phone										X
Eken-Södergård Karin and Cedervall Jessica	SYSAV	5 Jul	Personal			X	X						
Ekvall Kjerstin	NSR	4 Jul	Personal			X	X		X				
Erfors Lennart	Kristianstad municipality	12 Jun	Personal			X							
Gustavsson Niklas	Volvo Ab	25 Jul	Phone									X	
Hansson Lars	Lund University	2 Aug	Personal	X									
Horn Gunnel	Swedish EPA	28 Jun	Phone		X								
Johansson Gunnar	LRF Konsult	4 Jul	Phone					X					
Kåberger Tomas	Talloy	9 Jun	Phone										X
Lilliehöök Carl	Svensk Biogas	25 Jul	Phone							X	X		
Linne Marita	Biomil Ab	26 Jul	Personal										X
Persson Margareta	Swedish Gas Centre	27 Jul	Phone										X
Svensson Ronald	Trollhättan municipality, Swedish biogas association	28 Jul	Phone			X				X			X
FINLAND													
Arnold Mona	Technical Research Centre of Finland	11 Aug	Personal				X						X
Arpiainen Vesa	Technical Research Centre of Finland	8 Aug	Personal										X
Asplund Dan	Jyväskylä Innovation	16 Aug	Personal										X
Hietanen Lassi	Lassila & Tikanoja (private)	16 Aug	Phone				X						
Jormanainen Martti	Envipro Ky	24 May	Phone										X
Kalmari Erkki	Kalmari farm, Metener Oy	14 Aug	Personal					X	X				X
Kopalainen Sauli	YTV (public)	7 Aug	Personal				X						
Kurkela Esa	Technical Research Centre of Finland	10 Aug	Personal										X
Kutinlahti Heikki	MK Protech Oy	14 Aug	Personal										X
Latvala Markus	Bionova	7 Aug	e-mail										X
Lilja Raimo	Finnish Environment Institute, Ekoleima Oy	8 Aug	Personal		X								X
Lipsanen Juha	YTV (public)	6 Sep	e-mail										
Lundström Yrjö	Helsinki Water	7 Aug	Personal			X	X		X				
Malkamäki Matti	Greenenvironment Oy	18 Aug	Phone										X
Marttinen Sanna	Satafoods	7 Sep	Phone										X
Reskola Veli-Pekka	Ministry of Agriculture and Forestry	15 Aug	Phone		X								
Riikonen Arto	Gasum Oy	9 Aug	Personal								X		
Rintala Jukka	Jyväskylä University	15 Aug	Personal	X									
Väisänen Petri	Pöyry Energy Oy	14 Aug	Personal										X

Appendix 3 Economic and environmental aspects of raw material recovery for AD

Application of anaerobic digestion to **sewage sludge** and **industrial waste waters** is commonplace due to the fact that AD is a very competitive waste treatment alternative for biodegradable liquid waste. Research also shows that AD is an excellent method for the treatment of **manure** because it reduces nitrogen leaching¹⁵ from farm land, and improves the quality of manure as fertiliser by increasing the amount of plant available nitrogen while reducing odour (Berglund 2006). Digestion can also have positive environmental consequences when it is used to treat **harvest residues**. When nitrogen rich harvest residues are left on the field for the winter period, nitrogen is lost through nitrogen leaching and its conversion into ammonia (Malgeryd & Torstensson 2005, Berglund 2006). Recovery and digestion of harvest residues decrease these nitrogen losses and improve nitrogen efficiency (Lantz et. al 2005, Berglund 2006).

In addition to waste waters from households and industry, and agricultural waste, anaerobic digestion is often considered the most competitive waste treatment alternative for organic waste from **food industry**, especially in regions where waste streams from the food industry are relatively large and can provide a reliable supply of raw materials to the digestion process all year round (Erfors 2006, Eken-Södergård & Cedervall 2006). An additional incentive for the treatment of industrial waste can come in the form of gate fees (treatment charge that varies depending on the type of waste received) that the facility owner can charge from the producer of waste. However, as competition in the field of anaerobic digestion increases and its focus shifts from waste management towards renewable energy production, competition for raw materials usually increases, which eventually leads to lower gate fees being charged for the treatment of waste. It can also happen that waste eventually becomes considered a valuable industrial by-product that the owner of the biogas facility must pay for.

The use of **biodegradable waste from households** in the digestion process demands a separate system to be implemented for the source separation and collection of biodegradable waste from households, which is usually considered a costly investment (Ekvall 2006), though some studies show that the introduction of a separate collection for biodegradable waste can actually reduce the costs of the entire waste collection system (Favoino 2003). In addition, biodegradable waste from households often requires costly pre-treatment before it can be inserted into the digester. This allows the separation of undesired substances such as plastics and metals, which are a result of incomplete source separation, from the organic waste. The highest gate fees are usually charged for organic household waste (RVF 2005b) to compensate for the higher treatment costs.

The use of **park and garden waste** for digestion is in some instances considered problematic because, ideally, lignin-containing tree branches should be separated from grass clippings and leaves before digestion. It is for this reason that in Sweden, park and garden waste is usually composted. However, in the Netherlands digestion of park and garden waste is more common than in Sweden (Eken-Södergård & Cedervall 2006).

¹⁵ Nitrogen leaching causes eutrophication of nearby rivers, lakes or sea, which in some areas of Sweden has become a serious problem.

The costs associated with the cultivation of **energy crops** make them a more expensive raw-material than waste, and they are currently less frequently used for digestion than organic waste products. However, the use of energy crops for AD is expected to grow in the future due to the growing need for renewable energy sources (waste only provides a limited source of raw material to the digestion process). It should also be mentioned that dedicated energy crops do not require extensive pre-treatment. This cuts their treatment costs in the AD plant in comparison to organic waste from households, for instance.

Biogas yield varies between different types of raw materials. According to Berglund & Börjesson (2006), grease separator sludge provides the best (22GJ/dry tonne), and cow manure the poorest (6.2GJ/dry tonne) biogas yield per dry tonne. When looking at the biogas yields one should, however, also take into consideration the energy input into the system. Berglund & Börjesson have in their calculations taken into consideration the following energy inputs: transport of raw materials, handling of raw materials, biogas plant heating, biogas plant electricity, transport of digestate and spreading of digestate. Key figures related to the energy yields of different raw materials have been included in the table below.

Raw material	Estimated dry matter content (%)	Biogas yield (GJ/dry tonne)	Energy input (% of yield approx.)	Energy output (GJ/dry tonne)	Energy output (GJ per tonne of wet raw material)
Cow manure	8	6.2	36% (=2.2 GJ)	4	$0.08 \cdot 4 \text{GJ} = 0.32$
Pig manure	8	7	32% (=2.2 GJ)	4.8	$0.08 \cdot 4.8 \text{GJ} = 0.384$
Grease separator sludge	4	22	13% (=2.9 GJ)	19.1	$0.04 \cdot 19.1 = 0.764$
Ley crops	23	10.6	40% (=4.2 GJ)	6.4	$0.23 \cdot 6.4 = 1.472$
Municipal organic waste	30	12.4	26% (=3.2 GJ)	9.2	$0.3 \cdot 9.2 = 2.76$
Slaughterhouse waste	17	9.4	26% (=2.4 GJ)	7	$0.17 \cdot 7 = 1.19$
Tops and leaves of sugar beet	19	10.6	27% (=2.9 GJ)	7.7	$0.19 \cdot 7.7 = 1.463$
Straw	82	7.1	35% (=2.5 GJ)	4.6	$0.82 \cdot 4.6 = 3.772$

Source: Berglund 2006

Appendix 4 Technical aspects of biogas production

Anaerobic digestion technology that is used in the digester can be categorised according to four operating criteria. The first criterion is the **solid:liquid ratio** of the waste treated. When the loading of total dry solids (TDS) is below 15% a digester is considered wet and when TDS is above 15% it is considered dry (De Baere 2000). Higher energy yields can be achieved when TDS is above 15%. However, as the organic load rate increases it becomes technically more demanding to run the process smoothly.

The second criterion concerns the **temperature** at which digestion takes place. Conditions ideal for mesophilic bacteria are achieved when the reactor temperature is between 30–37 °C whereas thermophilic bacteria work best at approximately 55–65 °C. In general, it can be said that the higher the temperature the faster the degradation (Berglund 2006). It should, however, be pointed out that higher operating temperature demands a higher energy input for digester heat production.

The third criterion differentiates between **batch-wise and continuous operations**. In batch systems the digester is loaded at once and the whole reactor is emptied and loaded again when the digestion process has been completed after 2-3 weeks (Berglund 2006). In a continuous reactor, raw materials to the process can be fed in continuously at the same rate as digested residues are removed from the process. Batch-wise operations for solid waste have a simpler design and are less expensive than continuous operation digesters.

The fourth, and final, criterion defines **in how many steps the decomposition process is completed**. The two-phase process takes into consideration that anaerobic digestion actually occurs in several phases, the main ones of which are acid formation (acidogenesis) and methane formation (methanogenesis). Each of these processes makes use of different micro-organisms with different nutrition and optimal pH requirements (Berglund 2006). In a two-phase process the conditions for different types of micro-organisms are optimised leading to enhanced degradation (Nordberg 1996). As usual, technical demands on the two-phase process are higher than on the one-phase process.

Appendix 5 Biofuels and types of cars running on them

There are already various biofuel cars in the market. Ordinary diesel cars can be run on a mixture of ordinary diesel and biodiesel or on 100% biodiesel only. Biodiesel is produced from vegetable oils. It is quite common place to blend 5% of bioethanol in petrol, a mix which can be used in ordinary petrol cars. E85 is 85% bioethanol mixed with just 15% petrol. Only special biofuel enabled cars such as the Ford Focus flex-fuel or the Saab Biopower can run on E85. Normal petrol can also be used to run flex-fuel cars. One should know that bioethanol competes with biogas for raw materials used in its production process (e.g. sugar beet, wheat and corn).

Electric cars have a battery, which can be loaded through connection to the electricity grid. Just how environmentally friendly an electric car is depends on what primary energy inputs have been used to produce the electricity in the grid. Hybrid cars use either petrol or diesel oil as fuel but also have an electric battery, which can be loaded during driving using e.g. friction power from braking to load the battery. This electric power stored in the battery can then be used as an additional fuel to drive the car.

Gas vehicles have a two-tank system: one tank for methane gas (can be biogas or natural gas) and another tank for petrol. This is why 'biogas vehicles' are also referred to as bi-fuel vehicles. If the car was to run out of gas it automatically switches to petrol-mode.

(Miljöbilsportalen 2006)

Car manufacturers are developing new models of environmentally friendly cars at an accelerating speed. Some examples of the latest models close to commercialisation or already in the market have been demonstrated below:

- Volvo has introduced a new model, which runs on ethanol, methane, petrol or hythane (combination of methane and hydrogen gas).
- Toyota Prius Hybrid runs on liquefied petroleum gas (LPG) or alternatively methane but also has an electric battery. LPG is a by-product of natural gas production and oil refining.
- BMW has developed a car, which can burn both gasoline and hydrogen in its engine.
- Renault has developed a new type of hydrogen car where hydrogen production from water occurs in the car engine. Petrol, diesel oil or ethanol can be used for the production of hydrogen in this model.

(Helsingin Sanomat, 2006, June 17)

Appendix 6 Contribution of biogas to the achievement of Sweden's environmental quality objectives

Environmental quality objective	Role of biogas systems in achieving the objective
1. Reduced climate impact	Reduced GHG emissions from waste management. Replacement of fossil fuels with a renewable fuel. Avoided emissions of GHG from the production of chemical fertilisers.
2. Clean air	Use of biogas as vehicle fuel leads to reduced air emissions.
3. Natural acidification only	Reduced emissions of NO _x and SO ₂ when biogas replaces traditional vehicle fuels.
4. A non-toxic environment	Contribution to natural cycles through proper waste sorting at source, which allows for good quality compost and digestate to be used in agriculture.
5. A protective ozone layer	
6. A safe radiation environment	
7. Zero eutrophication	Reduced nutrient leaching (N, P) from arable land due to digestion of manure and plant residues. Replacement of chemical fertilisers with organic fertiliser. Reduced need for nutrients due to increased amount of plant available nutrients in digestate.
8. Flourishing lakes and streams	
9. Good quality groundwater	
10. A balanced marine environment, flourishing coastal areas and archipelagos	
11. Thriving wetlands	
12. Sustainable forests	
13. A varied agricultural landscape	Use digestate to facilitate restoration of pastures affected by fertiliser application.
14. A magnificent mountain landscape	
15. A good built environment	Contributes to the reduction of waste going to landfill. Achievement of the targets related to treatment of food waste through biological means. Use of renewable energy sources.
16. A rich diversity of plant and animal life	Diversity of plant and animal life is supported by fertile soil with adequate organic matter content.