Biogas in the United Kingdom & Sweden

A Technological Innovation System Based Analysis

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ABSTRACT
The production of biogas via anaerobic digestion is an effective technology for converting organic waste into renewable fuel. Using the Technological Innovation System (TIS) theory for assessing emerging technologies a comparison between the British and Swedish biogas sectors is carried out. There are seven components to a TIS allowing the sector to be broken down, a potential scheme for the connection of the functions is illustrated. The Swedish biogas sector is at a more advanced stage of development due to long-term governmental support both financially and through stringent environmental laws. Overall the Swedish government has been an effective system builder allowing the Swedish biogas sector to expand. The British biogas sector is conversely less advanced due to lack of this long-term support, although the scene is beginning to change as the government positions itself as a more effective system builder. Several lessons can be learnt from the Swedish biogas sector; long-term financial support for renewable energy is required and stringent organic waste disposal laws both encourage the development of biogas.

KEY WORDS
Technological Innovation System (TIS), biogas, anaerobic digestion, Sweden, United Kingdom
Table of Contents

1. Introduction.................................................................................................................. 1
   1.1 Background.............................................................................................................. 1
   1.2 Anaerobic Digestion............................................................................................... 2
   1.3 Use of biogas........................................................................................................... 3
   1.4 Biogas production and use in Sweden..................................................................... 4
   1.5 Biogas production and use in the United Kingdom................................................. 5

2. Theoretical Framework ................................................................................................. 5
   2.1 Technological Innovation System (TIS).................................................................. 6
      2.1.1 Actors.................................................................................................................. 6
      2.1.2 Networks.............................................................................................................. 7
      2.1.3 Institutions......................................................................................................... 7
   2.2 Functions of a TIS.................................................................................................... 7

3. Method........................................................................................................................ 11

4. Results......................................................................................................................... 13
   4.1 Function 1. Entrepreneurial Activity ................................................................. 13
      4.1.1 United Kingdom............................................................................................... 13
      4.1.2 Sweden............................................................................................................ 15
      4.1.3 Analysis............................................................................................................. 16
   4.2 Function 2: Knowledge development...................................................................... 17
      4.2.1 European Union.............................................................................................. 17
      4.2.2 United Kingdom............................................................................................. 18
      4.2.3 Sweden........................................................................................................... 19
      4.2.4 Analysis............................................................................................................ 20
   4.3 Function 3: Knowledge diffusion through networks.............................................. 20
      4.3.1 United Kingdom............................................................................................... 20
      4.3.2 Sweden............................................................................................................ 21
      4.3.3 Analysis............................................................................................................. 21
   4.4 Function 4: Guidance of the search........................................................................ 22
      4.4.1 European Union.............................................................................................. 22
      4.4.2 United Kingdom............................................................................................. 23
      4.4.3 Sweden........................................................................................................... 23
      4.4.4 Analysis............................................................................................................ 24
   4.5 Function 5: Market Formation................................................................................. 24
      4.5.1 United Kingdom............................................................................................... 24
      4.5.2 Sweden............................................................................................................ 25
      4.5.3 Analysis............................................................................................................. 26
   4.6 Function 6: Resource Mobilisation.......................................................................... 27
      4.6.1 European Union.............................................................................................. 27
      4.6.2 United Kingdom............................................................................................. 27
      4.6.3 Sweden........................................................................................................... 28
      4.6.4 Analysis............................................................................................................ 28
   4.7 Function 7: Legitimisation....................................................................................... 28
      4.7.1 United Kingdom.............................................................................................. 29
      4.7.2 Sweden........................................................................................................... 29
      4.7.3 Analysis............................................................................................................ 29

5. Discussion................................................................................................................... 30
5.1 Swedish biogas sector ................................................................. 30
5.2 United Kingdom biogas sector .................................................... 31

6. Conclusions .................................................................................. 32
7. References ..................................................................................... 34
List of acronyms

AD       Anaerobic Digestion
ADBA     Anaerobic Digestion and Biogas Association
Defra    Department for Environment Food and Rural Affairs
ETF      Environmental Transformation Fund
EPO      European Patent Office
EU       European Union
KLIMP    Klimatinvesteringsprogram (Climate Investment Program)
kWh      Kilowatt hours
KWth     Kilowatt hours thermal
REA      Renewable Energy Association
RHI      Renewable Heat Incentive
ROC      Renewables Obligation Certificate
RTFO     Renewable Transport Fuel Obligation
TIS      Technological Innovation System(s)
WWTP     Wastewater treatment plants
1. Introduction

Biogas in the UK is set to go through a large expansion in the coming years as more stringent waste and renewable energy targets come into force; alongside increased governmental support for biogas production and environmentally sustainable technologies in general. The UK is currently a large producer of biogas in European terms but has not particularly pushed the development of the technology as has been done in other countries such as Sweden. Newer technology allows biogas to be upgraded to a sufficient quality to be used as a vehicle fuel or injected into a natural gas grid. It is biogas upgrading that has lagged behind in the UK despite the large environmental benefits offered by the technology and the expanded use of the biogas offered.

The purpose of this project is to compare the biogas sectors in Sweden and the UK and provide measures that can be undertaken to improve the prospects for expanded use of the technology. Using the Technological Innovations Systems (TIS) theory for analysis of emerging technologies, the seven functions of the TIS will form an analysis for each country. The TIS theory is one of several related but distinct methods for analysing emerging technologies. It was chosen due to its previous use in analysing biomass and the holistic approach evident throughout the analysis. A stronger and more robust TIS encourages expansion of the biogas sector and conversely weaknesses discourages development. A potential link between the functions of the TIS has been developed to allow analysis of the whole TIS. The combination of theory and method will provide a comprehensive framework to underpin the analysis of the two countries.

The aim of this project is to perform analysis of the biogas sector in the UK and Sweden using the TIS framework and based upon the Swedish experience with biogas provide steps that can be taken to improve the prospects of the technology in the UK.

This project forms my thesis for a Master’s in Sustainable Development from Uppsala University. It is written as the final component of my master degree and as a project for Paul Steen from Ramböll in the UK. Through discussions with Paul Steen and my supervisor Åke Nordberg (SLU – Swedish Agricultural University) this thesis has developed into a study of the Swedish and UK biogas sectors. On a personal level I am interested in environmental issues in particular renewable energy, this thesis allows me to fulfil this interest.

1.1 Background

Modern lifestyles create large amounts of waste and consume finite fossil fuel reserves. This is not a sustainable situation. Technology that can mitigate our impact on the environment is available and commercially viable. The
production of biogas using anaerobic digestion (AD) of organic waste is one of these technologies. Biogas (methane) can be used in a variety of ways such as a vehicle fuel; the digestate (remains after digestion) of the AD process can be used as a fertiliser. Figure 1 shows the various material flows that are present when making biogas-using AD.

**Anaerobic digestion & biogas material flows**

![Figure 1](image1.png)

**Figure 1** Material flows present in the production of biogas from anaerobic digestion.

**1.2 Anaerobic Digestion**

AD is the process by which organic material is biologically degraded into a mixture, mainly compromising methane and carbon dioxide. Anaerobic bacteria carry out digestion in the absence of oxygen; the whole process consists of several stages (Figure 2).

![Figure 2](image2.png)

**Figure 2** The four-step process for the degradation of organic matter into biogas using anaerobic digestion. The steps are, hydrolysis, acidogenesis, acetogenesis and methanogenesis [1].

2
The first stage is enzymatic hydrolysis, this breaks down the particulate organic matter into soluble organic matter [1]. The second stage is acidogenesis it is carried out by two types of bacteria; this process then produces acetate, alcohols, volatile fatty acids, hydrogen and carbon dioxide [1]. The third stage acetogenesis is the production of acetate, hydrogen and carbon dioxide. The fourth and final stage is methanogenesis and can be carried out in two pathways: the aceticlastic or the hydrogenotrophic, with around 60% of the methane produced by the process coming from acetate [1].

AD is a biological process and can take place over a wide temperature range; the optimum temperature for AD depends on the bacterial populations used [2]. Moisture content can vary significantly from 50% to over 99% [2]. The feedstocks that can be used to generate biogas by AD are varied, including sewage sludge, agricultural waste, municipal solid waste and energy crops. Biogas can also be produced at landfill sites.

1.3 Use of biogas

Biogas can be used for applications designed to run on natural gas, but to do so it has to be cleaned of impurities and pressurised according to requirements. Raw biogas contains impurities such as carbon dioxide, water and hydrogen sulphide [3]. The impurities are removed to prevent corrosion and reduced mechanical wear on the machinery using the biogas. For biogas to be used as a vehicle fuel or be injected into the gas grid it must be upgraded which involves cleaning and pressurisation. There are several commercially available technologies that exist to upgrade biogas.

Pressure swing adsorption is a technology where carbon dioxide is separated from the biogas by adsorption on to a surface under higher pressure. The adsorption material is usually activated carbon that can subsequently be regenerated by reducing the pressure [3]. There is a series of several tanks containing the adsorption material running in parallel, when one tank becomes saturated, raw biogas flow is diverted to the next tank. Using this process nearly all of the carbon dioxide is removed. Hydrogen sulphide and water can severely damage the upgrading equipment and must be removed from the biogas before entering the upgrading equipment [3].

Absorption is a mechanism for the upgrade of biogas, is and is performed in three ways, water scrubbing, chemical scrubbing and organic physical scrubbing. The mechanism by which this technology functions is based upon carbon dioxide being more soluble than methane. Raw biogas meets a counter current of the absorption material; this results in higher concentration of carbon dioxide in the absorption material leaving the container and a higher concentration of methane in the biogas [3].

Cryogenic upgrading is a new technique that takes advantage of the distinct boiling and sublimation points of different gases in the raw biogas. Successive cooling cycles allow the various gases to be removed from the biogas [3].
1.4 Biogas production and use in Sweden

Biogas production in Sweden has remained fairly constant over the last few years, with production at WWTP contributing the largest share of biogas with 44% (605 GWh) of production [4]. Figure 3 shows the five categories of biogas production facilities showing the dominance of WWTP and landfill produced biogas. The relatively large proportion of landfill biogas production will decrease over the coming years as land filling of organic waste has been phased out [5].

As part of the Environmental Quality Objectives, there is a requirement that 35% of food waste from households, restaurants and retail premises shall be
biologically treated [6]. Biogas produced at WWTP is primarily used for heating and upgrading (Figure 4). To use biogas as a vehicle fuel or for injection into the gas grid water and carbon dioxide must be removed, as this increases the energy density of the biogas. There are several commercially viable technologies in place for biogas upgrading with others in the pilot and demonstration stages. [4]

1.5 Biogas production and use in the United Kingdom

Biogas production in the UK has been rising over previous years as shown in Figure 5 with by far the largest proportion of biogas being produced at landfill sites. The UK is one of the largest producers of biogas in the EU second only to Germany [7].

![Biogas production by facility type 2006 - 2009](image)

*Figure 5* Biogas production in the UK between 2006 and 2009. Production is dominated by landfill [8].

The large proportion of biogas generated by landfill will reduce in the coming years as the effect of the ban on the landfill of organic waste becomes apparent. Biogas production takes place at 151 WWTP facilities in the UK [9]. There is no comprehensive data compiling the use of the biogas from the WWTP in the UK although the EurObserver shows that the majority of biogas is used for electricity generation [7].

2. Theoretical Framework

In order to fully analyse and interpret the biogas sector in the UK and Sweden, it is necessary to utilise a theoretical framework. The theoretical framework that is to be used is that of a Technological Innovation System (TIS). Having been used to analyse bio-power in Sweden [10], biogas in Switzerland [11] and biomass in Germany [12] has a proven record in analysis.
of emerging technologies. The TIS method allows the sector to be broken down into seven functions that can be analysed independently of each other and subsequently brought together to provide an overall analysis of the TIS itself. An alternative theory based upon similar principles as TIS is the multi-level framework, this theory and TIS have been compared and contrasted [13]. The TIS method was chosen because as it provides greater analytical power over the multi-level framework [13] and has been shown as an effective method to analyse emerging technologies [12].

2.1 Technological Innovation System (TIS)

A TIS can be defined as “...a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilisation of technology.”[14]. Using a TIS based approach allows the analysis of social and political aspects of an emerging technology to be included. A TIS is comprised of three elements: actors, institutions and networks as shown in Figure 6. The three components of the TIS are completely interconnected and interdependent upon each other. The members of an individual TIS are not necessarily exclusively part of one TIS and can be a member of multiple TIS.

![Figure 6 The overlapping and interconnected components of a TIS system.](image)

2.1.1 Actors

Actors are companies and organisations. For a biogas TIS this would involve utility companies, biogas plant manufactures, engineering consultancies and construction companies. Organisations cover bodies such as universities, professional associations, NGO’s and governmental departments [10] each company or organisation that enters the TIS brings new knowledge, resources and capital. The new entrants do one or more of, fillings gaps in the technology, meeting novel demands, or test new combinations of the technology [10]. As time progresses and more and more actors join an emerging TIS, a division and specialisation of labour is formed. Actors have
varying degrees of influence the most important being the ‘prime mover’ which is a political, economic or financial position to strongly influence the direction an emerging TIS takes [15].

2.1.2 Networks

Networks are the mechanism through which knowledge is spread through the TIS. Networks can be classified into two different types of which both are required. Learning networks are networks between user-supplier, university-industry, or between competition companies, these networks tend to be built around the market [10, 15]. The network influences the actor’s perception of what is desirable and possible within the TIS, guiding investment decisions. The second type of network is one that seeks to influence the political agenda in the advancement of the TIS [10]. As more actors join an emerging TIS the networks become stronger and the collective voice louder providing additional incentive for more actors to participate.

2.1.3 Institutions

Institutions are the legal and regulatory aspects affecting the TIS as well as the norms and rules regulating interactions between actors [10]. Institutions provide the ‘rules of the game’ for the specific technology.

2.2 Functions of a TIS

The functions of a TIS are the activities that take place within the TIS resulting in technological change. The activities have a function to contribute to the objective of the TIS namely in the maturity of the system [15]. In the literature there is no consensus agreement on the number of functions of a TIS, Hekkert et al provide an overview of the literature and propose seven functions of a TIS which shall be used in this paper [16].

Within each function of a TIS there are performance indicators that are used to determine the strength of that particular function. The performance indicators are shown in tables 1 and 2 are generic to any emerging technology and the specific performance indicators used in this work will be outlined in table 3. Using the performance indicators it will be possible to repeat this study and monitor the performance of the biogas sector.
<table>
<thead>
<tr>
<th>Number</th>
<th>Function Title</th>
<th>Description</th>
<th>Performance Indicators</th>
</tr>
</thead>
</table>
| 1      | Entrepreneurial activity        | Entrepreneurial activities are essential in an emerging TIS as they develop the new knowledge into a technology and see its future market potential [16]. Entrepreneurs take financial risks to experiment with new and uncertain combinations of technology, of which not all will be successful. Entrepreneurs can be broadly categorised into two groups: new entrants who have a vision of novel future markets for the technology or incumbent companies seeking to diversify into emerging technologies [16]. | • New entrants  
• Diversification activities of incumbents |
| 2      | Knowledge development           | Knowledge development or learning is a major part of a TIS. Described as “the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning” [16], its role is at the heart of a TIS. Knowledge development sources are not only limited to ‘learning by searching’ such as R&D within companies and academia but encompasses ‘learning by doing’. | • R&D projects  
• Investments in R&D  
• Patents |
| 3      | Knowledge diffusion through networks | The exchange of information between actors is an important function. Knowledge must be able to efficiently pass from R&D projects to the government and the market. This allows governmental policy to keep abreast of the latest developments and the market enabling more efficient direct investment [16]. The diffusion of knowledge is not just a one-way street with government and the market helping to steer R&D projects towards the ever-changing norms and values of the TIS [16]. | • Workshops  
• Conferences |
| 4      | Guidance of the search          | An emerging TIS will often compete with other emerging TIS’ for a share of a limited pool of research investment. Whether a specific emerging TIS is given a larger share of this investment is determined by the preferences of industry, government and the market [16]. | • Targets for use of biogas |
### Table 2 Functions of a TIS and their performance indicators

<table>
<thead>
<tr>
<th>Number</th>
<th>Function Title</th>
<th>Description</th>
<th>Performance Indicators</th>
</tr>
</thead>
</table>
| 5      | Market Formation   | For an emerging TIS a market may not exist for the technology or it has difficulty competing with existing technologies [16, 17]. Rosenberg stated that “Most inventions are relatively crude and inefficient at the date they are first recognised as constituting a new innovation...they may offer only very small advantages, over previously existing techniques.” [18]. Therefore an emerging TIS needs to be protected and nurtured, there are two options available to achieve this, the first is the creation of a niche market for the technology and the second is to create a temporary competitive advantage through a policy and tax regime that is favourable to the technology [16, 17]. | • Niche markets for biogas  
• Tax and policy that encourages biogas |
| 6      | Resource Mobilisation | The input of financial capital is an essential basic resource and contributes to all the other functions, a lack of resources will hinder the development of the TIS [16]                                                                                       | • Venture capital  
• Government funding of R&D |
| 7      | Legitimisation      | For an emerging technology to develop it has to gain acceptance and become part of the current regime or overthrow the incumbent regime [16]. This change is not universally welcome and tends to be opposed by the proponents of the incumbent technology. Legitimisation comes through advocacy coalitions, the purpose of which is to put the technology on the agenda, acquire resources and secure a favourable tax policy [16]. | • Lobbying groups  
• Perception of biogas |
3. Method

The analysis will be based upon work by Negro and Hekkert in their paper on innovation system functioning [12]. In this paper the authors research biomass in Germany looking at the functions and how they have been promoted or not in a historical context rather than as a current comparison between two national TIS as in this thesis.

Table 3 Functions of a TIS and their indicators to analyse function vitality.

<table>
<thead>
<tr>
<th>Function</th>
<th>Performance Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1. Entrepreneurial activity</td>
<td>• Membership increase of trade organisations such as: ADBA, REA Biogas, Energigas Sverige</td>
</tr>
<tr>
<td></td>
<td>• Diversification of incumbent companies into the biogas sector</td>
</tr>
<tr>
<td>F2. Knowledge development</td>
<td>• Registration of patents related to biogas</td>
</tr>
<tr>
<td></td>
<td>• Number of biogas R&amp;D projects</td>
</tr>
<tr>
<td></td>
<td>• Investments in biogas R&amp;D</td>
</tr>
<tr>
<td>F3. Knowledge diffusion through networks</td>
<td>• Biogas conferences</td>
</tr>
<tr>
<td></td>
<td>• Biogas workshops</td>
</tr>
<tr>
<td>F4. Guidance of the search</td>
<td>• Governmental targets for use of biogas (EU and national)</td>
</tr>
<tr>
<td>F5. Market formation</td>
<td>• Existence of niche markets for biogas</td>
</tr>
<tr>
<td></td>
<td>• Policy incentives for biogas</td>
</tr>
<tr>
<td></td>
<td>• Tax incentives for biogas</td>
</tr>
<tr>
<td>F6. Resource mobilisation</td>
<td>• Availability and accessibility financial capital for the biogas sector</td>
</tr>
<tr>
<td>F7. Legitimisation</td>
<td>• Growth and success of lobbying</td>
</tr>
<tr>
<td></td>
<td>• How biogas technology is viewed</td>
</tr>
</tbody>
</table>

Each function has a set of indicators that can be used to analyse the strength or weakness of that function relative to the other country. Table 3 above outlines the indicators that will be used to analyse each function it is based upon an analysis of the TIS theory [16] and its application [15], both of these papers have the same author.
The connections between the individual functions are important in the analysis of the TIS as a whole as they complement the strength or weakness of the function itself.

For the subsequent paragraph please refer to Figure 7 (below).

- Starting with F4 there is a target set by the government (i.e. landfill directive)
- This leads to entrepreneurial activity F1
- Then to knowledge development F2
- This knowledge is then diffused through the network F3
- Knowledge diffusion F3 brings in new entrepreneurs stimulating F1, also promoting further knowledge development F2.
- As knowledge develops F2 and R&D projects are successful, this encourages resource mobilisation F6 to the TIS and legitimises the technology F7
- Increased legitimisation and resource mobilisation lead to market formation F5 as the technology is seen as an appropriate solution to the target outlined in F4
- As market formation develops (F5) there is an increase in companies entering the system promoting F1
- Once the market is fully formed targets may be adjusted to promote technological advancement of the system
- Increased activity in F1 will lead to the perception that the technology is legitimate F7

![Functions of a TIS](image)

**Figure 7** Potential scheme for the connections between the functions of a TIS. Based upon work by Hekkert and Negro [14].
The connections between the functions are not always necessarily positive. A failure of R&D projects (F2), could lead to a perception that the technology is not viable and not worth committing resources (F6) to resulting in a lack of market formation. In a case such as this, there may be a need for the F1 companies to carry out more research or for there to be a change in the target F4.

The strength or weakness of a TIS is determined by the connections it is composed of.

A limitation to this study is the availability of directly comparable data sets for all analysis sections. Where ever possible directly comparable data will be used but where this is not possible the best available data will be used. My own personal knowledge of the Swedish language is an additional limitation, but due to the large amount of information available in English this is not foreseen as a problem that will affect the conclusions of the study.

4. Results

This section will contain the analysis of the national TIS of the UK and Sweden.

The analysis will be split into the seven identified functions and then split into the national analysis of the UK and Sweden. As both countries are members of the EU, the EU will be included in the relevant function analysis.

4.1 Function 1. Entrepreneurial Activity

Analysing the publically available membership data of the trade organisation representing biogas and anaerobic digestion of the respective country assesses this function.

4.1.1 United Kingdom

Formed in 2009 with ten founder members, ADBA is a UK trade association representing companies involved in AD and biogas [19]. Within six months membership had grown to 90 and by April 2011 stood at over 200. The membership covers a wide range of companies and governmental departments. The REA is another trade association for companies involved in all aspects of renewable energy, one the component sector groups is of interest to this study namely the Biogas Group. The Biogas Group was formed when the Biogas Association became part of the REA in 2002 [20].
Both associations have seen great increases in membership figures particularly for ADBA, which has grown rapidly since its foundation. Membership of REA biogas has doubled in the 2008 to 2011 period (figure 8). Using membership data from the REA the size of the companies involved can be inferred from the membership category the company has. Corporations of all sizes make up around 80% of the REA Biogas membership, with the majority of companies falling into the ‘Small Corporate’ category (figure 9). The average year that a member joined the REA is shown in table 2; it is important to note this does not necessarily mean the member joined the biogas group at the same time. Six of the members of the REA biogas group had joined the REA prior to the creation of the biogas group. This shows evidence of diversification of incumbent companies into the biogas TIS. Large corporate companies led the way in membership of the biogas group, on average joining in 2003. This is followed by intermediate corporate, medium corporate and small corporate (table 4).
This data was collected from the ADBA and REA biogas websites. For ADBA the current member directory was used to provide 2011 data and announcements made in the ADBA newsletter concerning membership figures were used to provide the 2009 and 2010 data. The information available from the REA website was more comprehensive showing the exact date the member joined, type of membership and REA sector involvement.

<table>
<thead>
<tr>
<th>Membership Category</th>
<th>Mean Year Joined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Corporate</td>
<td>2003</td>
</tr>
<tr>
<td>Intermediate Corporate</td>
<td>2004</td>
</tr>
<tr>
<td>Medium Corporate</td>
<td>2006</td>
</tr>
<tr>
<td>Small Corporate</td>
<td>2009</td>
</tr>
<tr>
<td>Non Corporate</td>
<td>2010</td>
</tr>
<tr>
<td>Associate</td>
<td>2007</td>
</tr>
<tr>
<td>Corresponding</td>
<td>2005</td>
</tr>
</tbody>
</table>

4.1.2 Sweden

Energigas Sverige is the Swedish trade organisation for the gas industry in general. In 2004 biogas was split from natural gas into a separate section of the organisation resulting in the creation of the Biogasportalen (Biogas portal). There are six regional biogas associations: Biogas Öst (east), Biogas Väst (west), Biogas Syd (south), Biogas Sydost (southeast), Biogas Mitt (midlands) and Biogas Norr (north). Table 5 shows the founding dates for the various regional biogas associations.
Table 5 Information on the regional biogas associations in Sweden, showing their founding date and sources of financing. * Founding date of Biogas Sydost parent organisation.

<table>
<thead>
<tr>
<th>Name</th>
<th>Year Founded</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas Väst</td>
<td>2001</td>
<td>Public &amp; Private Funding</td>
</tr>
<tr>
<td>Biogas Öst</td>
<td>2007</td>
<td>Public &amp; Private Funding</td>
</tr>
<tr>
<td>Biogas Mitt</td>
<td>2009</td>
<td>Public &amp; Private Funding</td>
</tr>
<tr>
<td>Biogas Norr</td>
<td>2003</td>
<td>Public &amp; Private Funding</td>
</tr>
<tr>
<td>Biogas Syd</td>
<td>2005</td>
<td>Public &amp; Private Funding</td>
</tr>
<tr>
<td>Biogas Sydost</td>
<td>1999*</td>
<td>Public &amp; Private Funding</td>
</tr>
</tbody>
</table>

Energigas Sverige has a diverse membership, with a significant proportion of members being utility companies and governmental institutions such as municipalities. Car manufactures such as Volvo, General Motors and Mercedes-Benz are represented giving examples of diversification into the biogas TIS. The six regional associations are members of Energigas Sverige. There is no publically available data, giving data of membership acquisition or membership category available from Energigas Sverige.

Biogas Väst operates in western Sweden (county of Västra Göteland) and contains the major city of Gothenburg. Founded in 2001 with ten members the membership currently stands at over 60 [23]. Biogas Väst was the first regional biogas association to be formed and its model has been copied by some of the other regional associations. The preliminary study for Biogas Öst specifically cites the Biogas Väst model as a good example of a regional association [24]. The success of regional biogas associations particularly Biogas Väst and Syd in attracting KLIMP funding led for calls for a similar organisation to be created for eastern Sweden ultimately leading to Biogas Öst [24]. Biogas Väst has been successful in attracting new companies into the organisation and has greatly increased the use of biogas in the region; for biogas use as a vehicle fuel there has been over a ten-fold increase in production in the first decade of Biogas Väst.

The regional biogas associations have taken advantage of both public and private funding and seeking funding from the EU. The drive to set up a regional biogas association in some cases has been driven by publically owned municipal energy companies; this was the case with Biogas Öst [25]. The creation of regional biogas associations across the country is an indication that there is an increase in entrants into the Swedish biogas TIS.

4.1.3 Analysis

The biogas associations in both Sweden and the UK have seen an increase in membership over the last decade. In both countries a national industry organisation has expanded to cover the biogas sector, this step occurring earlier in the UK. No direct data was publically available giving dates of membership acquisition for companies and organisations in Energigas Sverige or the regional associations. Information from Biogas Väst shows the great expansion in membership, and this combined with the creation of other regional biogas associations is taken as an indication that there is an
Increasing number of companies entering the Swedish biogas TIS. Membership data from Energigas Sverige indicates the presence of incumbent companies expanding into the biogas TIS, the best examples of this are the car manufacturers seeking a new fuel source. REA Biogas membership records the date a company becomes a member of the organisation. Between 2000 and 2006 there was a steady increase in members, this increase accelerated after 2007 nearly tripling membership in 2011 relative to 2006 figures. With ten companies joining REA Biogas in the first four months of 2011, 2011 looks set to be a record year for entrants into the UK biogas TIS. REA Biogas data suggests the first companies to move into the biogas TIS were large companies who were most likely looking to diversify. Later years, entrants were characterised by smaller companies.

Overall, there is an increase in entrants to both of the national biogas TIS and both show evidence of diversification of companies into the biogas TIS. The presence of the regional associations in particular the pioneering Biogas Väst is an important driver of regional growth of the biogas TIS. These regional associations make it easier for new and existing companies to enter the market.

### 4.2 Function 2: Knowledge development

Analysing the number of patents granted to companies concerning biogas and anaerobic digestion, alongside feasibility studies and R&D projects assessing this function. All are considered positive values. The EPO database was searched using the advanced search function, searching using the relevant term in both the title and the abstract of the patent entry. When using the EPO database only European published applications were searched.

#### 4.2.1 European Union

Using the search terms ‘biogas’, ‘anaerobic digestion’ in the EPO patents search function gives a proxy to the amount of patentable research being carried out by UK based companies. Figure 10 shows the number of patents using the search term ‘biogas’ in the EPO database; German applicants mainly dominate biogas patents. UK applicants for biogas patents make up less than 1% of the total. When searching the database using the term ‘anaerobic digestion’ there is a similar picture emerging as with ‘biogas’ with domination from German applicants (figure 10).

Using the same search terms in the EPO database shows that few patents containing ‘biogas’ or ‘anaerobic digestion’ come from Swedish applicants. Using the IEA Task 37 list of suppliers two of the 15 companies supplying biogas-upgrading equipment are based in Sweden.

IEA Task 37 maintains a list of biogas upgrading suppliers; only one of the 14 companies is based in the UK, Germany having the most with four biogas-upgrading suppliers based there.
The country locations of the biogas-upgrading suppliers are illustrated in figure 12.

![Figure 10 Patents issued by the EPO related to the search term biogas][26].

### 4.2.2 United Kingdom

ADBA publishes a newsletter to its member organisations, within these newsletters there are only two newsletters that refer to an investment in R&D [27]. WRAP is delivering the government's Anaerobic Digestion Demonstration Programme which ran until March 2011 this programme has supported five projects previous to this the now defunct regional development agencies and the carbon trust have provided support to biogas R&D [28, 29]. Data specific to UK investment in biogas R&D was not available but data is available for the UK economy as a whole. The UK spends around 1.9% of GDP on R&D this is slightly less than the EU average and far behind the Lisbon target of 3% (figure 11).
4.2.3 Sweden

Sweden's spending on R&D across all sectors is 3.62%; this is higher than the EU 27 average and above the Lisbon target of 3% (figure 11). Engerigas Sverige has extensive information available about R&D projects and has the main focus of 'increasing the production and use of biogas by developing improved techniques' [31]. R&D projects are can be placed into four focus areas: thermal gasification, biogas from landfill, improved distribution and industrial applications [31]. There are currently 33 biogas research projects supported by public funds such as municipalities, universities and government agencies such as the Swedish Energy Agency [32].

Figure 2 Gross domestic expenditure on R&D. The red line shows the Lisbon target of 3% [30].

Figure 12 Location of biogas upgrading suppliers. Giving an indication of where advanced biogas application research is being undertaken [3].
4.2.4 Analysis

A weakness identified searching the EPO database with specific search terms is only patents containing the search term will be returned, this presents some difficulties in acquiring comprehensive data. The search terms used and the location of gas upgrading companies strongly point towards Germany as the hub for biogas R&D. There are more companies offering biogas upgrading facilities based in Sweden than the UK but the numbers are so small that it is hard to draw conclusions from such data, although it is worth noting that the UK economy is around five times larger than Sweden's [33]. Swedish R&D spending as a percentage of GDP is one of the highest in the EU and well above the target of 3%. This is in contrast to the UK, which is below the EU average and well below the Lisbon target.

There are 33 publicly funded R&D projects related to biogas in Sweden currently in operation; information about these projects are easily assessable and shows the aims of these projects. These projects cover the whole spectrum of biogas use from transportation to improved digestion techniques, to international cooperation. Publically funded biogas R&D in the UK is limited in terms of awareness; the ADBA newsletter only briefly mentions R&D projects taking place.

There is a stronger knowledge development in the Swedish biogas TIS, this is a product on a national scale of a greater investment in R&D, strong public support for R&D projects and regional networks bringing key players together.

4.3 Function 3: Knowledge diffusion through networks

This function is assessed by the number of workshops and conferences related to the technology. Higher numbers of these show greater levels of knowledge diffusion in the networks as actors have the chance to come together to exchange and present ideas.

4.3.1 United Kingdom

ADBA organises conferences specifically for the AD and biogas sector. The first conference was held in December 2010 and ADBA aims to double the size of the 2011 conference, which is to be held in July 2011. The 2010 conference included speakers from several government departments, banks, and utility companies [27]. A similar range of speakers is planned for the 2011 conference [34]. Part of the 2011 conference will be a series of workshops focusing on development and operational success.

ADBA has several working groups that bring together experts in subsectors of the industry initially beginning with four groups and has seen an expansion to eleven working groups [35]. The working groups are led by the member
organisations and meet bi-monthly; ADBA actively encourages the working groups to co-operate [35]. ADBA has also began to organise members luncheons, three of which have taken place so far [35].

REA biogas organises bi-monthly one-day general meetings for members of the biogas group [36]. REA Biogas runs a five-day biogas course aiming to cover biological processes, plant design, maintenance and safety, with engineers from Germany forming the core of the course [37].

There are other organisations involved in spreading knowledge these include chartered institutes such as the chartered institute of wastes management. With the biogas sector crossing into so many disciplines it was felt necessary to concentrate on the main players e.g. ADBA.

4.3.2 Sweden

The Nordic Biogas Conference brings together the biogas companies from the Nordic countries (Sweden, Norway, Denmark, Finland and Iceland). At the Nordic Biogas Conference there is a comprehensive programme of presentations covering many aspects of biogas and includes a study tour [38]. To date there have been three conferences with the next planned to take place in 2012.

Biogasportalen collates the conferences and seminars related to biogas that occur in Sweden and Europe [39]. These conferences and seminars are organised by the regional biogas associations and by Energigas Sverige (Biogasportalen’s parent organisation). Calendars available on the regional biogas associations show additional study visits and regional seminars [25, 40]. With several conferences and workshops occurring every month there is a strong network between the actors in the Swedish biogas allowing for effective distribution of knowledge through the TIS.

Biogassyd, which operates in the Skåne region of Sweden, takes advantage of its geographical location and position in the Danish-Swedish Öresund region to work with companies and organisations in Denmark [40, 41].

4.3.3 Analysis

In both the Swedish and British biogas TIS, there is a strong diffusion of knowledge with many seminars and workshops occurring each month. A strength of the Swedish system is that it has seminars and workshops at both regional and national level, this allows regionally specific problems to be addressed. ADBA’s approach to working groups is to have a diverse number of groups and allow them to be led by members. This gives strong direction to the work. Working groups meet a few times a year so with eleven groups and working on the assumption each group meets three times a year there are potentially 33 working group meetings per year. This total does not include the luncheons and the annual conference.

Overall, there is a similar level in the UK and Sweden of workshops and
conferences allowing an efficient diffusion of knowledge. Importantly governmental departments attend and give presentations. This allows knowledge about the current state of the market development, R&D, and how governmental targets are impacting on the TIS development to become available to the government. Governmental representation is important at these workshops to ensure if needed, adjustments can be made to other functions of the TIS for further stimulation.

4.4 Function 4: Guidance of the search

This function is analysed by assessing specific targets set by the government and industry regarding the use of the technology as this provides the target of guidance for the research. The EU has an important role to play in this function and will included in analysis.

4.4.1 European Union

There are EU targets that drive the guidance of the search for a biogas TIS, these targets drive the guidance of the search in different manners.

The landfill directive (1999/31/EC) aims to prevent and reduce the negative impact on the environment the landfill of waste causes. Article 5 of this directive sets out a target for reducing the landfill of biodegradable municipal waste to 35% of 1995 levels and specifically mentions biogas production as a mechanism to achieve this goal [42]. Members were allowed to extend these goals by up to four years if greater than 80% of waste was disposed of via landfill [42]. Within two years of publication of the directive member countries were required to submit national plans outlining strategies to meet these targets. The UK opted to take advantage of the allowance in the directive to delay the attainment of the target by four years, Sweden did not use this facility [43].

The renewable energy directive (2009/28/EC) has important implications on the biogas TIS giving renewable energy targets to the EU as a whole and to the member states individually [44]. This directive gives a target of 20% renewable energy generation of the EU as a whole by 2020, within this are country specific targets Sweden has a target of 49% and the UK 15% [44]. By 2020, 10% of energy for transportation should come from renewable sources, with biofuels produced from waste such as biogas counting two times for national obligations. For renewable gas the directive stipulates that transmission and distribution tariffs must not be discriminated against providing it meets technical specifications. Gas network infrastructure should be extended where necessary to facilitate the injection of biogas. Compulsory sustainability criteria are required by biofuels, in this section biogas produced from waste scores extremely well, giving a 73% saving in greenhouse gas emissions [44].
4.4.2 United Kingdom

The 2010 UK election resulted in the formation of a coalition government bringing together the Liberal Democrats and the Conservatives. The coalition agreement is a document that states the aims of this government. In this document there is an aim to greatly increase energy from waste through anaerobic digestion [45]. Awaiting publication is the new anaerobic digestion strategy, to be published in late May 2011 [46]. This strategy will build upon the previous strategy published in 2010 [28]. In 2009 Defra published its shared goals for anaerobic digestion in 2020; there is an aim to have anaerobic digestion as an established technology producing biogas that can be used for heat power and transport fuel with the digestate being used as an organic fertiliser [47].

The RHI launched in 2011 provides major incentives for the use of renewable energy. The RHI provides support for biogas installations of up to 200 kWh and supports a range of source materials, all waste used to produce biogas will be eligible for the scheme [48]. Unlimited support is provided to upgrade biogas for injection into the gas grid within the RHI scheme.

4.4.3 Sweden

A major target driving the guidance of the search for the Swedish biogas TIS is the environmental code. The Swedish Environmental Code is composed of 16 national environmental quality objectives [49]. The code originally containing 15 objectives came into force in 1999; it is an amalgamation of fifteen previous acts [50] and has since been updated to sixteen objectives [51]. There are two sections of the environmental code, which apply to biogas. In the section 'A Good Built Environment' there is a stipulation that by 2010, 50% of waste will be recycled using materials recovery, this includes biological treatment. At least 35% of food waste from all sources except food processing plants will be recovered by biological treatment by 2010. Biological treatment is the only option for food waste originating at food processing plants. By 2015, 60% of phosphorus compounds in wastewater are required to be recovered and used on productive land.

The Swedish state energy agency published a national strategy on biogas in 2010; this document outlines the government’s aims for the technology [52]. The production of biogas is recognised as being uniquely placed amongst other renewable technologies as it beings to close the cycle. It recommends urban public transportation as an effective use of biogas as it can reduce pollution levels in cities. Biogas production will be encouraged most where the greatest benefit is identified producing it from, sewage, food waste and manure [52]. Potential for expansion of biogas is identified as being able to increase from the current levels of 1.5 TWh to 3 or 4 TWh [52].
4.4.4 Analysis

The EU provides a significant proportion of the guidance for the development of a biogas TIS. The landfill directive specifically mentions biogas production as an important mechanism to reduce the landfill of municipal organic waste. These targets promote the development of anaerobic digestion of varied food waste products. The renewable energy directive promotes biogas as a renewable energy source and as it is produced from waste it receives one of the highest sustainability criteria available for a biofuel. The EU targets promote the two major technical components of the biogas production system, firstly the anaerobic digestion component via the landfill directive and secondly the use of the biogas as a renewable fuel.

Both the Swedish and British governments have an action plan for the development of biogas in their respective countries; these documents lay out the proposed future of the technology. Both governments realise the importance that biogas plays in the future energy mix. Biogas is recognised as having a prominent role as it can uniquely address two major sustainability issues, namely the reduction of waste and reduced dependence on fossil fuels.

From a governmental perspective the Swedish government has placed more stringent targets on the landfill of waste and the biological treatment of food waste. Tied into this are other targets, whilst not specific to biogas production encourage it, such as the phosphorus-recycling target. These targets have driven forward the use of biogas production in Sweden; it is a technology that can address more than one sustainability issue at the same time. The decision by the UK government to delay the implementation of the landfill directive will have hindered development of biological treatment of waste techniques.

4.5 Function 5: Market Formation

This function will be assessed by the quantity of niche markets of the technology, alongside policy and tax regimes that encourage the development of the technology.

4.5.1 United Kingdom

There are no niche applications of the technology used to produce and upgrade biogas.

There are several policies and tax regimes that have been implemented by the British government to promote the development of biogas and thereby contribute to market formation.

The RHI is the major new policy that affects the production of biogas. Biogas combustion of less than 200 kWth is supported at a tariff rate of £0.065 per kWh, with the tariff duration lasting for 20 years [48]. It is important to note
this tariff does not apply to the production of biogas from landfill. The RHI supports the injection of biogas into the gas grid but provides no further incentives for its use once in the gas grid.

Table 6 The differing levels of support given to various technologies used to produce biogas (ROC scheme).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Level of support ROC / MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill gas</td>
<td>0.25</td>
</tr>
<tr>
<td>Sewage gas</td>
<td>0.5</td>
</tr>
<tr>
<td>Fuel made using AD</td>
<td>2.0</td>
</tr>
</tbody>
</table>

A ROC is a green certificate issued to the generator of renewable electricity. The aim of the ROC system is to increase the percentage of renewable electricity generated with targets provided for each year. Electricity suppliers who are unable to generate enough electricity to fulfil their obligations must pay into a fund providing payment to those who have fulfilled their quota. Levels of support vary by technology and production process table 6 shows the various support levels related to biogas [53].

Table 7 The differing levels of support given to various technologies used to produce biogas (Feed-in-tariffs).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Tariff 2011-2012 (KWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD &lt;500kW</td>
<td>£0.121</td>
</tr>
<tr>
<td>AD &gt;500kW</td>
<td>£0.094</td>
</tr>
</tbody>
</table>

Feed-in-tariffs are used to support small scale (>5 MW) renewable energy generation. Anaerobic digestion is one of the supported technologies in this scheme, which is designed to last for 20 years. Table 7 shows the support given to anaerobic digestion processes [54].

The RTFO although primarily designed for liquid biofuels supports the use of biogas as a transportation fuel. The production of biogas for use as public transportation fuel is supported [55].

4.5.2 Sweden

The Swedish government has put in place several policies and tax regimes to stimulate development of biogas in Sweden, contributing to the market formation function of the TIS.

The electricity certificate system (Elcertifikatsystemet) promoting the generation of energy from renewable sources was first introduced in 2003 [56]. Electricity suppliers must source a percentage of their electricity from renewable sources; if a company does not reach its annual quota it must
purchase certificates to cover the shortfall [57]. Certificates are given to producers of renewable energy and they are able to sell on their excess certificates, one electricity certificate is worth one MWh of electricity. This systems allows the producer of renewable energy to profit from the initial sale of the electricity and secondly from the sale of the electricity certificate. This scheme is designed to run for 30 years and individual plants are eligible to claim through this system for up to 15 years [57]. Although, some heavy industries are exempt from the requirements of the electricity certificate scheme [31].

The energy taxation system is the other major incentive program, it includes taxes on: energy, carbon dioxide and sulphur.

Energy and carbon dioxide tax are not levied on renewable energy generation, with consumers paying a combined electricity tax. The energy certificate system provides the incentives for the electricity producers to use renewable energy as tax exemptions on production were not seen as a viable proposition [31]. When biogas is used for heating purposes there is no energy taxation applicable and as biogas is exempt from carbon dioxide taxation this levy is not applied either. Carbon dioxide neutral vehicle fuels such as biogas are exempt from tax this gives biogas a competitive tax advantage against fossils fuels such as petrol and diesel.

On a local level there some incentives for the use of biogas cars which are exempted from tolls in Stockholm (ends August 2012) and exempted from parking charges in some municipalities [31]. There are other schemes to promote an infrastructure related to biogas including requirements the availability of alternative fuels at refuelling stations.

4.5.3 Analysis

Both the national governments of Sweden and the UK provide policy and tax incentives for the use of biogas. These incentives are not solely designed for biogas but support biogas as part of a larger renewable energy incentive. There are some similarities and differences to the approaches taken by the governments with some of the schemes so new it is not possible to fully assess the impact they will have.

The British ROC and the Swedish electricity certificate system run along similar principles allocating a renewable energy quota and providing certificates, which can be sold on. The ROC system provides support for various types of biogas production but with the highest level of subsidy going to processes that produce fuel. The exemption provided to heavy industries from the certificate system will have a negative impact on the whole system and thus the development of the biogas market as part of the larger renewable energy mix.

The RHI is the first of its type in the world and it will be interesting to see how
effective the scheme is at promoting renewable heat generation. An important aspect of the RHI is the support given to the injection of biogas into the gas grid allowing a wide distribution of the gas as the majority of urban areas in the UK are linked to the gas grid.

The Swedish approach to energy taxation has been to reduce taxes or make exemptions for renewable technologies. Some of the tax incentives run for rather short periods such as subsidies provided to gas powered cars, which will only run for another two years.

Both national governments provide tax relief and policy incentives to use and produce biogas. The unique properties of the biogas system are recognised by the governments with biogas strongly supported.

4.6 Function 6: Resource Mobilisation

This function is assessed by the availability and accessibility of financial capital (venture capital, government funding of R&D and experimental pilots of the technology).

4.6.1 European Union

The EU has strict rules concerning state aid to companies, and ideally companies should provide the capital for R&D. It is however accepted that the market can fail to provide sufficient levels of R&D to fully develop a technology and in this type of incidence state aid may be required [58]. There are some criteria that an applicant for state aid must fulfil in order to receive funding, namely that the aid must address a well defined market failure, be well targeted and minimise market distortion [58].

4.6.2 United Kingdom

The British government is investing in R&D projects with three to six AD plants being funded by the ETF [29].

Rather than providing grants the British government has chosen to use an incentive scheme, which doesn’t provide the initial capital but provides financial support for a set period of time. The RHI is the first of its type in the world.

As part of the 2010 coalition agreement, there was an agreement on the creation of a green investment bank [45]. The aim of the bank is provide financial capital for investments in low carbon infrastructure such as renewable energy generation [59]. The bank is scheduled to be set up in 2012 with capitalisation of £3 billion in the year 2013-2014 [60]. Until 2015-2016 the bank will be unable to have borrowing powers from this time onwards the bank will be able to raise private finance in addition to the £3 billion provided by the government [60].
4.6.3 Sweden

There are several ways financial capital can be introduced into the biogas TIS, namely via public and private funds. The success of this funding is dependent on the accessibility and availability of the funds.

The climate investment program (KLIMP) created in 2003 provides funds for long-term investments that reduce emissions and is scheduled to finish in 2012 [61]. In total, the expected grants paid out by the investment programme to the circa 2700 projects will be over 8 billion SEK [61]. Around a quarter of KLIMP grants have been awarded to private companies, and around a third of the total KLIMP grants have been awarded to biogas projects. The now closed local investment programme was a precursor to KLIMP and issued grants of 6.2 billion SEK in the 1998 to 2002 period [62].

Municipalities, universities and government agencies such as the Swedish Energy Agency provide public money for biogas research projects of which there are currently 33 [32].

4.6.4 Analysis

Investment in renewable energy is risky and often private financing for renewable energy projects can be difficult and expensive to acquire. This is especially true of new and developing technologies. This constitutes a market failure and governments step in and provide funds for investment. Government finance is provided on a targeted basis using specific funds, such as the KLIMP system in Sweden and the future green investment bank in the UK.

Sweden has a long history in providing finance to renewable energy projects, first though the local investment programme which invested 6.2 billion SEK (c. £0.6 billion) then secondly through the KLIMP programme which will invest over 8 billion SEK (c. £0.8 billion). With the creation of the green investment bank in the UK with its significant capital (although still far short of the financing required to meet carbon reduction targets) and its future ability to raise private finance will create a large financial resource for the financing of renewable energy projects.

Currently there is much greater public financing in the Swedish biogas sector through research programmes and existing investment programmes. Although it is important to note that the KLIMP scheme will terminate in 2012. The UK is behind Sweden currently but will begin to gain ground as the green investment bank begins operations.

4.7 Function 7: Legitimisation

The method to assess this function is rather subjective but it is achieved by assessing the rise and growth of lobbying groups and their actions.
4.7.1 United Kingdom

One of the aims of the government in the national biogas strategy is to have biogas production as an established technology [28] implying that the technology is not currently viewed as a completely legitimate solution.

As part of the coalition agreement there has been a commitment to the expansion of biogas production [45].

Biogas production was the only technology that had its incentive increased in value as part of the RHI consultation process.

4.7.2 Sweden

Biogasportalen and its parent body Energigas Sverige represent the national professional association for the gas industry. On a regional scale there are several organisations, which cover most of the country these regional organisations are members of Energigas Sverige. Biogasportalen via Engerigas Sverige promotes the use of natural gas and biogas.

Around a third of the KLIMP grants were awarded to biogas facilities [61] showing that the technology is viewed as a legitimate technology for renewable energy generation and waste management. The high penetration of biogas plants and the expansion of biogas upgrading facilities shows that the industry views the technology behind the biogas production as a legitimate one, allowing companies to meet their environmental targets.

4.7.3 Analysis

Biogas has a higher penetration and is used for more diverse applications in Sweden than in the UK. It is viewed as a more legitimate technology for the processing of organic waste and the generation of renewable energy. The government has invested significantly in the biogas production process through R&D programmes and financial incentives.

The UK government has an objective to have the biogas production process as an established technology, and has recently begun to invest in biogas R&D programs.

Overall this function is stronger in Sweden than the UK. As the industry expands and there are greater renewable energy investments from both the public and private sector this function will become stronger in the UK biogas TIS.
5. Discussion

The biogas TIS in Sweden is stronger than in the UK as the individual functions that comprise the TIS are stronger. Table 8 shows which of the individual functions are stronger and Figure 7 shows potential connections between the functions. The Swedish biogas TIS is stronger in four of the seven functions and even in the other three with the UK. Although in many areas the UK has implemented policies that will begin to strengthen these functions this, in turn will strengthen the whole biogas TIS.

Table 8 Relative strengths and weaknesses of biogas functions between Sweden and the UK. A (+) indicates this is a stronger function and a (-) indicates this is weaker. An (=) indicates the functions are equal in strength.

<table>
<thead>
<tr>
<th>Function</th>
<th>Sweden</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1. Entrepreneurial activity</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>F2. Knowledge development</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>F3. Knowledge diffusion</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>F4. Guidance of the search</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>F5. Market formation</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>F6. Resource mobilisation</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>F7. Legitimisation</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

The TIS method and theory has proved to be a useful and informative mechanism to analyse the biogas sectors in both the UK and Sweden. All seven functions of a TIS were found to be present in both national biogas sectors with some functions being weaker and stronger when compared to the other country. The TIS method has allowed a complex and diverse sector to be broken down into sections and analysed at this level. Bringing the previously analysed functions together allows a comprehensive discussion of the biogas sectors and effective comparison to be undertaken. A proposed mechanism for the way in which the functions of a TIS connect and influence each other is illustrated in figure 7.

5.1 Swedish biogas sector

F4 is a strong component of the Swedish TIS and is an important driver of the whole TIS giving the target that the technology must meet. This is a strong component because of several factors (Swedish environmental law and the EU landfill directive) targets that influence the development of biogas. Strict environmental laws and waste management has forced the development of the commercial operation of AD plants. It is recommended that biogas be used to produce fuel as it gives the greatest environmental benefits and improves fuel security; this promotes the use and development of upgrading technology. The three-way push from F4 promotes F1 as companies move into the biogas TIS to fulfil the requirements of F4. There is a financial incentive as targets from F4 are legally binding (i.e. EU landfill directive). These F1 companies then invest in R&D of which some projects are successful and some are not. Government support provided for R&D
increases the chances of success. Within this function state aid can be easily targeted at an identified market failure. A recent example of this is the €24 million granted by the Swedish government to Göteborg Energi AB to develop biogas from forestry industry residues [63]. F3 begins to develop when there are enough companies and organisations, they will begin to communicate ideas between themselves on research that has been successful and research that has not. In Sweden the regional trade associations are important components of F3, building networks on a local level. The trade associations communicate success back to the government. The subsection of functions 1 to 3 is very important to nurture at the formation stages of the TIS as the technology will be competing in an arena in which there is an incumbent technology or competing solution to the problem identified in function 4.

F7 develops, as F2 R&D projects are successful and the technology begins to be seen as a legitimate technology for the fulfilment of F4 by both government and industry. Steps are then taken by the government to meet F4 this has been achieved through the use of KLIMP and LIP funding schemes. A positive F7 promotes further F1 development as more companies see market opportunities. Alongside F7 development F6 occurs with resources becoming mobilised to the biogas sector. F2 shows that technology is commercially viable; this is then financially assisted using KLIMP and LIP. As a technology becomes more established and outcomes more certain, there is less need for public financing of the technology and private finance should then provide all of the financial capital required. This step will happen soon as the KLIMP scheme is scheduled to conclude in 2012.

As resources (F6) become available and legitimisation (F7) develops, steps have again been taken by the government. These include the electricity certificate system that give biogas a competitive advantage over traditional fossils fuels. Tax incentives have been given to use biogas-powered vehicles, which has promoted F1 bringing car manufactures into the TIS.

By targeting several of the functions of a TIS the Swedish approach has been an effective system builder for biogas in Sweden. Biogas with this support is now an established technology in Sweden.

5.2 United Kingdom biogas sector

F4 is a weaker component of the biogas sector in the UK because of delays in the implementation of key targets such as the EU landfill directive. This reduced emphasis on finding solutions to waste management issues will have reduced the drive to develop technologies to comply with the landfill directive. In F1 there has historically been less development, this is possibly due to a lack of drive from F4, providing less incentive for companies to move into biogas. The biogas sector has been experiencing a period of great expansion as membership of REA biogas and ADBA increases. Overall R&D is lower within the British economy than is required by the Lisbon treaty; there has been a general lack of the more advanced biogas technologies such as
upgrading although this situation is now changing. Through the ETF the government is now funding an AD demonstration programme this will increase the strength of F2 in the UK biogas sector. The setup of biogas and anaerobic digestion specific trade organisation (F3) came rather late but ADBA especially has seen a great deal of expansion in its members.

F7 has in the past been a weak section of the biogas sector, but this is beginning to change as AD was specifically mentioned the coalition agreement of 2010 with measures being provide to increase the penetration of AD. The current view is that AD is not an established technology in the UK this could be due to the fact there has been less R&D projects that have spread positive knowledge about technology. A contributing factor may be the lack of governmental financial support for the technology.

Resource mobilisation (F6) has been an issue thus far, UK has one of the highest productions of biogas in Europe but has been severely lacking in the more advanced applications of biogas such as vehicle fuel and gas grid injection. The ETF and the green investment bank will bring financial resources into the biogas sector. Given the positive governmental attitude towards biogas in the coalition agreement hopefully the green investment bank will give high priority to biogas and associated technologies.

New schemes such as the RHI and older schemes such as the ROC system, give competitive advantage to renewable technology such as biogas. This promotes the strength of F5. Increased RHI credit when compared to other renewable technologies gives increased financial advantage to producers of biogas. Large support is given to fuel generated from biogas.

The lack of intervention in several functions and less ambitious targets have stunted development of the biogas sector in the UK. Steps are now being taken to address this, with functions such as F6 expected to strengthen as more financing becomes available through the green investment bank. The British government has not historically been a good system builder for biogas in the UK but this is changing and biogas is set to go through a major expansion in the UK in the coming years.

6. Conclusions

The Swedish biogas sector is at a more advanced stage of development. This is due to stricter laws governing waste management combined with financial support for the technology from the government. This sector is at a suitably advanced stage that some governmental financial support is able to be withdrawn. Although financial support is still provided to specific R&D projects, allowing further expansion of the sector. The Swedish government has over many years proved to be an effective system builder; intervention in several areas has been integral to this. Market failures such as finance availability have been addressed through schemes such as KLIMP. The EU provides funding for regional biogas trade organisations, which are effective local organisations.
The British biogas sector has had less support from the government, which is crucial for the development of a technology such as biogas production. A parallel issue was the delay in the implementation of the landfill directive, which has given less impetus for the development of the technology. This situation is beginning to change as the ETF and the green investment bank provide support to several of the functions of the TIS. There is increasing interest in the technology; this is shown in the expansion of trade organisations for biogas.

To allow the expansion of biogas in the UK several lessons can be learnt from the Swedish experience. The major lesson is that support for an extended period of time is required, and this support needs to be provided for by the government. Strict environmental laws encourage the use of new technologies to solve problems stemming from pollution. Organisations such as ADBA should lobby for more stringent targets for organic waste disposal and those encouraging the biological treatment of waste. Companies should take advantage of finance made available through the green investment bank once it begins operations, as waste is one of the targeted areas. The investments made by the green investment bank should give private financiers more confidence in renewable technology as an investment, provided of course the facilities financed, are successful. Trade organisations should observe the success of the regional biogas associations in Sweden and consider duplicating these successful organisations. Now that biogas produced for vehicle fuel receives such significant RHI credit efforts need to be made to bring vehicle manufactures into the biogas sector.

If steps such as those outlined above are carried out the scene is set for the breakthrough of biogas technology in the UK.
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