Stockholm Environment Institute, Project Report - 2011

Governance of Innovation for Sustainable Transport

Biofuels in Sweden 1990-2010

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Cover Photo: Biofuel bus, Sweden © LetIdeasCompete/flickr

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PREFACE

This report is a result of the GIST (Governance of Innovation for Sustainable Transport) project, performed under the auspices of IMIT (Institute for Management of Innovation and Technology) between 2009 and 2011. The first step of the GIST project was the development of a framework for analysing the governance of innovation systems, published as a journal article (Hillman *et al.,* 2011). Parallel to that work, two primary case studies were initiated that were supposed to contribute to framework development and to the understanding of the connection between governance and innovation processes. The overall case focus of the project is innovations for sustainable transport, and more specifically low-carbon road vehicles and fuels. This case study report on biofuels was written by Karl Hillman (IMIT and University of Gävle), with support from the other researchers involved in the GIST project: Annika Rickne (University of Gothenburg and IMIT), Måns Nilsson (Stockholm Environment Institute and Royal Institute of Technology), and Thomas Magnusson (IMIT and Linköping University). Some of the data was collected at Chalmers University of Technology in 2004-2005 by Karl Hillman (then named Jonasson) in cooperation with Björn Sandén and Hanna Jönsson (now at the Västra Götaland Region).

EXECUTIVE SUMMARY

Biofuels have been proposed as part of the solution to a number of societal and environmental problems, such as the increasing oil price, air pollution and global warming. Over the years, a range of governance arrangements have been introduced to stimulate development, diffusion and use of vehicle fuels produced from renewable resources, principally biomass. This report applies a recent framework to investigate how various arrangements influenced the functionality of the innovation system for biofuels in Sweden 1990-2010. The framework takes its departure in the technological innovation system (TIS) approach, which is complemented with input from literatures on socio-technical transitions and governance.

The innovation system for biofuels in Sweden comprises a number of specific technologies. First generation biofuels mainly refer to ethanol from starch and sugar, biodiesel from vegetable (and animal) oils, and biogas from organic waste. These are either imported or domestically produced and available on the market, and they are used in different kinds of road vehicles. By contrast, second generation biofuels are yet under development and the first commercial products are expected in the coming years. These will typically be produced through fermentation or gasification of cellulosic biomass, resulting in, e.g., ethanol, methanol, DME, FT-diesel and methane (‘biogas’).

On a general level, the Swedish innovation system for biofuels functioned relatively well, in that progress was achieved regarding the scale and scope of activities, and the working of processes necessary for system development. First generation biofuels went from vehicle tests to a significant share of the fuel market for buses and cars, while a number of second generation technologies were researched, and a few concepts are now aimed at commercialisation. On a more detailed level, there is reason to believe that functionality of the studied innovation system could have been even stronger. What is striking about the case is that governance played a decisive role for most activities and that there were little resources and experimentation originating from private actors alone. This may have created a system that were more or less dependent on governance support, and that discouraged private initiatives. As a result of strong market formation and slow progress for second generation biofuels, we also see that legitimation of first generation biofuels was central. However, late in the studied epoch when legitimacy weakened, biofuels was generally defamed.

The development of the Swedish innovation system for biofuels can be partly explained by the influence of external factors that were not specific for biofuels. In fact, environmental issues and the increasing oil price were the main driving forces supporting biofuels. While the fuel and vehicle regimes were hesitant to start with, the field was promoted by stakeholders related to agriculture, pulp and paper, and various municipal responsibilities, such as waste, water and public transport. Introduction was helped by the existence of related technology for natural gas vehicles, and the production and use of fuel ethanol and biodiesel in other countries. However, there were also competing technologies that reduced the interest in biofuels, such as more fuel-efficient diesel and petrol vehicles, and electrification resulting in hybrids, plug-in hybrids and electric vehicles.

While governance in relation to biofuels in Sweden was largely influenced by external factors, it was in turn crucial for the development of the innovation system. Knowledge development concerning new technologies and the related supply of economic resources were largely the result of programmes with a significant share of public involvement. Furthermore, market formation for first generation biofuels hinged upon an increasing number of governance arrangements at multiple levels since around year 2000. Still, biogas suffered from high costs and the lack of strong organisations. Finally, a number of public recommendations, strategies and directives on national and EU levels aimed to influence the direction of search towards biofuels, and particularly those of the second generation. However, ongoing market developments – supported by governance – and sustainability debates somewhat counteracted such initiatives. In future discussion, this kind of potentially underestimated effects needs to be taken into consideration.

From the studied case, we learn that a seemingly well functioning innovation system may show a range of deficits when analysed in more detail. Due to limited resources there is always the question of how to prioritise time and money. In the case of biofuels in Sweden, there seem to have been over-attention towards market formation for first generation biofuels, which means that resources were more needed in relation to RD&D of second generation biofuels. This could have reduced expectations on first generation biofuels as a long term solution and pushed new technologies further ahead, possibly easing the legitimacy backlash for biofuels at the end of the epoch. In general,

there is a problem when key processes come 'out of phase', such as when the ambitions regarding new technologies expressed in policy documents was not reflected by actual market developments and research results. Part of the explanation for this is that the effect of governance on various alternatives was to a high degree determined by technology status. Hence, it remains a challenge for future governance to take into account the different and shifting stage of development of alternative technologies.

1 INTRODUCTION

In recent decades, biofuels have been proposed to solve a number of problems in the transport sector. In times of unsecure supply and high price of oil, biofuels offer possibilities for new supplies of fuels and even domestic production. Also, biofuels may introduce a number of environmental advantages as compared to fossil fuels, such as petrol and diesel. Importantly, governed adequately the field of biofuels for road vehicles can help reduce emissions of air pollutants, as well as net carbon dioxide (CO_2) emissions contributing to global warming.[1] The present report aims to contribute to understanding the connection between governance and innovation, in order to support future decision-making on specific innovations. Our case study concerns the technological innovation system (TIS) for biofuels in Sweden between 1990 and 2010, which also includes the related development of vehicles that can be fuelled by biofuels; these are commonly called 'clean vehicles' or 'clean cars'.[2] The main research question (MQ) addressed in the report is:

MQ In what way did various governance arrangements influence the functionality of the innovation system for biofuels in Sweden between 1990 and 2010?

Each TIS is typically conditioned by a particular mix of governance arrangements that intervene in the TIS, both as part of the context and more specifically infusing political or market signals into the system. However, governance is to some extent also part of the system itself, reproducing patterns of influence (Leach *et al.,* 2007). In this report, we are primarily interested in governance arrangements aimed at enhancing the functionality of the particular TIS, and that were orchestrated by public actors alone or in combination with others.

A secondary aim of this report is to test and contribute to the development of a recently proposed framework for analysing the governance of innovation systems (section 1.2 and Hillman *et al.,* 2011). Accordingly, the work with the main question was very much guided by that framework, which brings focus to the connection between governance arrangements and a number of key processes necessary for the development, diffusion and use of a particular technology (Bergek *et al.,* 2008a; Hillman *et al.,* 2011). More generally, TIS functionality is determined by activities emerging from its constituting elements, under the influence of external factors on different socio-technical levels. The framework helps us formulate a number of sub-questions (SQ) supportive in answering the main question. First, to analyse how governance influenced TIS functionality, we need knowledge on the overall functionality and what generally determined this, as captured by two sub-questions:

SQ1 Did Sweden have a well functioning innovation system for biofuels, i.e., were all key processes present and did they develop in a positive direction?

SQ2 How did external factors influence innovation system functionality?

Then we need to find out what governance arrangements were present in the studied epoch. Furthermore, the framework enables us to develop what we mean by 'in what way' governance had an influence (from the MQ); this brings in a division into specific key processes and alternative technologies, as well as the aspect of sufficiency with regard to the strengthening of TIS functionality. In addition, it can be asked how the influence of governance was moderated by external factors.

SQ3 What governance arrangements were present in the innovation system?

SQ4 What key processes (and technologies) did the arrangements address and did they address those processes that needed most support?

SQ5 How did external factors affect the influence of governance arrangements on innovation system functionality?

In cases where there is a large number of governance arrangements implemented, as expected from the present case, it may be valuable to reflect upon governance on a more aggregated level instead of discussing each arrangement separately. Here, the categorisation of arrangements described by the framework opens for the identification of types of arrangements based on various dimensions (presented in the Appendix).

1 Notably, there are also examples of production and use of biofuels that is potentially more harmful than fossil fuels.

2 The Swedish term used is 'miljöfordon' or 'miljöbilar', which directly translates to environmental vehicles or cars. In recent years, vehicles with low consumption of conventional petrol or diesel were also included in these terms.

The boundaries of system studies are always to some extent arbitrary, and also in this case study the geographical, the technological, as well as the temporal boundaries require some explanation. First, regarding the geographical delimitation the global character of any TIS makes it difficult to study a separate country. However, in the studied period the development of biofuels in Sweden was largely determined by actions taken by policy makers, firms and customers within the country; influence from abroad was mainly in the form of imported vehicles and fuels. Furthermore, the Swedish influence on foreign development was limited.[3] Taken together, this would justify a national system boundary, treating some factors as external influence.

Second, concerning the technological boundaries of the study, the main interest for society would be the development of increasingly better biofuels, and not the success of one specific alternative. Furthermore, the interaction between different biofuel technologies were extensive, thus motivating the study of those as a common system, instead of a number of fuel specific systems (Sandén and Jonasson 2005; Sandén and Hillman 2011). Also, connections between biofuels and *other alternative fuels and vehicle technologies were much weaker than between biofuels.*[4] It should also be acknowledged that the use of biofuels and clean vehicles is a means to reduce the environmental impact of road transport, but it is not a goal in itself. The starting point in this case study is the analysis of the biofuels TIS; as there are also other means to reduce the environmental impact, it is not given that poor functioning of this biofuels TIS is a bad thing for the environment.

Finally, the motivation for the choice of time period to study is that there was little governance directed towards biofuels in Sweden before 1990, although with a few exceptions (see also section 3). First, in the first half of the 20th century ethanol was sometimes blended into petrol to remedy for scarcity of oil. Second, in relation to the 1970s' oil crises, R&D of mainly fossil methanol production and use was launched by the Swedish government in cooperation with vehicle manufacturers. Third, for a few years in the early 1980s the farmers' organisations produced ethanol from grains in a pilot plant, and the ethanol was blended into petrol in the Mälardalen region. Fourth, a few buses were running on ethanol in Örnsköldsvik since the mid-1980s. Having said this, the actors and activities from before 1990 have little impact on our analysis; it was around 1990 that there were multiple concurrent governance arrangements exclusively directed towards biofuels. Accordingly, our analysis covers the period from 1990 until the time of writing in early 2011.

The present report is structured as follows. This section continues with an overview of the field of biofuels (section 1.1) and a description of the research design (1.2). Then, in section 2, the studied TIS is presented in a chronological account, with biofuel governance (answering SQ3) and industry activities, and relevant external factors on various levels. The key processes and technologies addressed by governance arrangements (SQ4) are analysed in section 3. At the end of that section (3.8), the questions on overall functionality (SQ1), and the influence of governance (SQ4) and external factors are elaborated (SQ2 and SQ5). Finally, the main research question is addressed throughout section 3 and in the concluding section 4, which also contains a discussion of the research design. A categorisation of governance arrangements that could be used in further analyses is offered in the Appendix.

1.1 BIOFUELS

The area of biofuels is made up by several competing or complementary technologies; their value chains all start with a biological material (called biomass), and the end product is used for propulsion of vehicles. Biofuels are so-called 'alternative fuels', a term commonly used for all fuels that are substitutes to petrol or diesel. This includes both fossil and renewable fuels, where biofuels are examples of the latter. The vehicles partly or fully dedicated to an alternative fuel (or electricity), are often denoted 'clean vehicles'.[5] Biofuels and clean vehicles are usually referred to being *sustainable technologies,* primarily entailing that the environmental burden caused by their production and use is lower than for conventional fuels and vehicles. We will analyse the TIS for biofuels in Sweden, which could be regarded as divided into four alternative technologies defined by their respective value chains: biodiesel, biogas,

3 It may be argued that this situation is beginning to change as biofuel volumes increase and Sweden serve as an example for other countries.

4 Some examples of other technologies are vehicle electrification, hydrogen and fuel cells, and natural gas.

5 In recent years, cars with low consumption of conventional fuels have also been included. The Swedish term used is 'miljöfordon', which translates to 'environmental vehicles'.

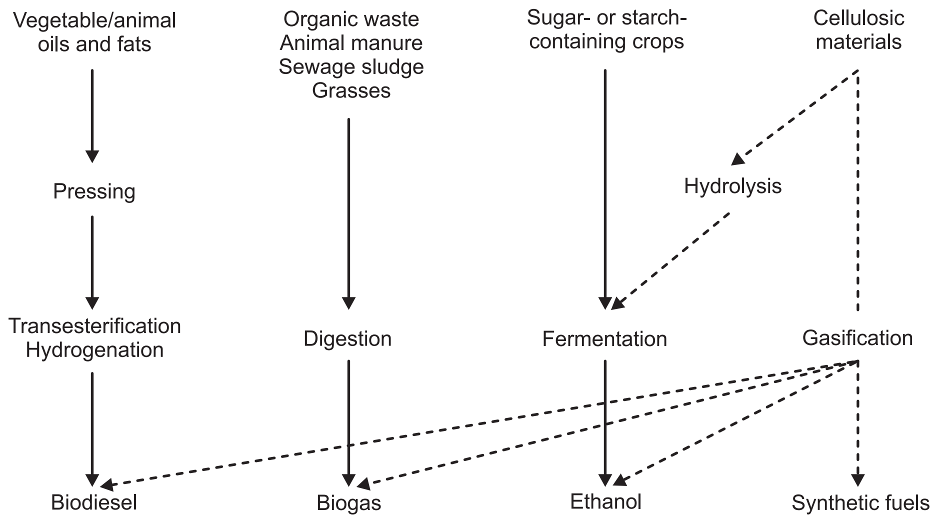

Figure 1: Biofuels and their respective value chains, i.e., raw materials and production processes (modified, Hillman 2008)

Unbroken lines indicate existing paths, while dashed lines represent paths that are under development. Oils and fats, sugar and starch, and cellulosic materials may also be derived from residues and waste.

ethanol and synthetic fuels (see Figure 1).[6] In addition, these alternatives are often divided into a first and a second generation, largely reflecting whether they are commercially available (unbroken lines in Figure 1) or under development (dashed lines), respectively. With this division, all of the synthetic fuels, as well as cellulosic ethanol, are referred to the second generation. The biofuels and their use as vehicle fuels are generally described below.

First, the term biodiesel is commonly used to denote a range of biofuels based on vegetable (or animal) oils and fats. The most basic form of biodiesel is pure oil, and a more advanced fuel consists of transesterified oil, called FAME (fatty acid methyl ester). FAME is produced in many parts of the world, e.g. from soybean, sunflower, rapeseed and palm oil. At the end of the studied epoch, another method to process oils and fats to produce biodiesel, called hydrogenisation, was commercialised.

Second, first generation ethanol is produced through fermentation of sugar- or starch-containing crops. Brazil and USA are the largest producers of fuel ethanol, using primarily sugar cane and corn, respectively. In Europe, grains and sugar beet are the mostly used resources for ethanol production. In a number of countries, research is carried out regarding hydrolysis of cellulosic materials (e.g. wood and agricultural residues), which could make such materials accessible to production of second generation ethanol.

Third, biogas is produced through digestion of many different resources, such as sewage sludge, animal manure, agricultural by-products and waste, and cultivated grasses. As these resources are not suited to be transported over long distances, biogas is often locally produced. The most widespread use of biogas is related to stationary installations, such as heat and electricity production, but upgrading and use as vehicle fuel is increasing in some countries. Biogas is basically made up by the same chemical compound as natural gas, i.e. methane, which allows for common technology.

Finally, there is a range of synthetic fuels that can be produced through gasification of almost any carbon containing material, including biomass of various kinds. For example, cellulosic materials, such as wood and residues from forestry and agriculture can be gasified, and the resulting components can be synthesized into methanol, DME (dimethyl ether), Fischer Tropsch (FT) diesel ('second generation biodiesel'), methane ('biogas') and possibly also ethanol. However, gasification processes are still under development, being part of R&D programmes around the world.

The supply (import and domestic production) and use of biofuels were part of a general strategy to replace fossil fuels with renewable energy in Sweden, and in the studied epoch biofuels use increased from

6 Here we leave out hydrogen and electricity, which could also be produced from biomass. These can be viewed as separate systems, with ongoing governance.

almost zero to 5.6 per cent of the road transport fuels: 3.0 per cent ethanol, 1.9 per cent FAME (mainly rapeseed methyl ester, RME), and 0.7 per cent biogas (Swedish Transport Administration 2011).[7] As long as biogas was produced from residues and waste, it was by many actors viewed as the most sustainable biofuel available in Sweden. However, ethanol and biodiesel technologies were generally less expensive than those for biogas. Even more expensive then were second generation biofuels – synthetic fuels and cellulosic ethanol – that are still under development and not available on the market. For many years, these alternatives have been considered more promising than first generation ethanol and biodiesel as regards sustainability aspects, such as production potential, energy efficiency, and net emissions.

Biodiesel can be used in conventional or slightly adjusted diesel engines, or be blended into conventional diesel. Blending levels are generally determined by the quality of the biodiesel, and how well it corresponds with fuel standards and vehicle requirements. Ethanol can be used in the same way as biodiesel, but then in petrol engines, or blended into conventional petrol. To be able to use high-level ethanol blends, though, vehicles need to be equipped with, e.g., flexible fuel (or flexifuel) technology. Such vehicles can use any mixture of petrol and E85 (i.e., 85 per cent ethanol and 15 per cent petrol). In addition, for heavy vehicles, the diesel engine was modified to be able to use almost pure ethanol. Concerning biogas, it can only be used in vehicles dedicated to methane, of which some also have a tank for petrol (called bi-fuel vehicles).[8] Finally, the synthetic fuel FT diesel can be used as biodiesel and methanol is similar to ethanol, while DME requires dedicated vehicles that are yet under development.

1.2 RESEARCH DESIGN[9]

One of the starting points for the report was to apply the theoretical framework proposed by Hillman *et al.* (2011) on the present case. The framework is based on the technological innovation system approach (TIS) for analysing technological change (Hekkert *et al.,* 2007; Bergek *et al.,* 2008a). A TIS is typically defined as a socio-technical system aimed to enhance the development, diffusion and use of a particular technology, and it can be described by its constituting elements: knowledge and artefacts, actors, networks and institutions (Bergek *et al.,* 2008a; Bergek *et al.,* 2008b). Actors may act individually, but central to the idea of innovation systems are the networks linking these actors, and the inherent knowledge and resource flows. Innovation is not an isolated activity but a collaborative process involving many actors on various levels – firms, universities, authorities and non-governmental organisations (NGOs), as well as less formal associations – located spatially close or far apart. They can relate to the studied technology in various ways, for example as suppliers, producers, users or policy makers. Underlying the knowledge and artefacts, actors and networks is a set of institutions: 'the humanly devised constraints that structure human interaction', i.e. 'the rules of the game' (North 1994: 360-361). The system elements are mutually interrelated in a number of ways. Actors and networks form and carry out institutions, while institutions are embedded in artefacts and guide actors' actions and perceptions. Knowledge and artefacts shape and constrain institutions, while also setting conditions for what actors can do. Finally, external factors are interpreted through the elements within the TIS, thus determining the actual influence of such factors on the system (Sandén *et al.,* 2008).

An innovation system is far from linear, but characterized by multiple feedback loops and external influence. To capture system dynamics TIS scholars describe a number of key processes – system functions – necessary for the overall function of developing, diffusing and using a particular technology or knowledge area (Table 1) (Bergek 2002; Bergek *et al.,* 2005; Hekkert *et al.,* 2007; Bergek *et al.,* 2008a). Structure and key processes are thus different, but complementary, ways to study a system. It is suggested that the performance of a system may be evaluated analysing its outcome in terms of the status of the key processes over time; the aggregated result is termed the functionality of the TIS. In many recent studies, key processes are more or less replacing structures as indicators of system performance, while structures are included to describe what is changing.

The applied framework consists of three principal sets of variables: the governance arrangements, the functionality of the TIS, and external factors. We consider the governance challenge being to address weak system processes (Bergek *et al.,* 2008a) and we assume that governance arrangements, over time, influence functionality in different ways. In this, we view the sets of variables as connected through a

7 Percentages are based on energy contents.

8 Methane is the main component of biogas and fossil natural gas.

9 This sub-section is for the most part a summary of Hillman et al. (2011), though with some modifications.

Table 1: Key processes (functions) in technological innovation systems

(based on Bergek *et al.,* 2008a: 414-419)

Key process	Description
Knowledge development and diffusion	The generation of breadth and depth of the knowledge base of the TIS, and the diffusion and combination of knowledge.
Influence on the direction of search	The existence of incentives and/or pressures for actors to enter the TIS, and to direct their activities towards certain parts of the TIS.
Entrepreneurial experimentation	The probing into new technologies and applications in an entrepreneurial manner.
Market formation	The articulation of demand, the existence of standards, and the timing, size and type of markets actually formed.
Legitimation	Legitimacy is a matter of social acceptance and compliance with relevant institutions.
Resource mobilisation	The extent to which the TIS is able to mobilise competence/human capital and financial capital.
Development of positive externalities	The generation of positive external economies, such as pooled labour, knowledge spillovers, specialised intermediate goods, and complementary products, services and infrastructure.

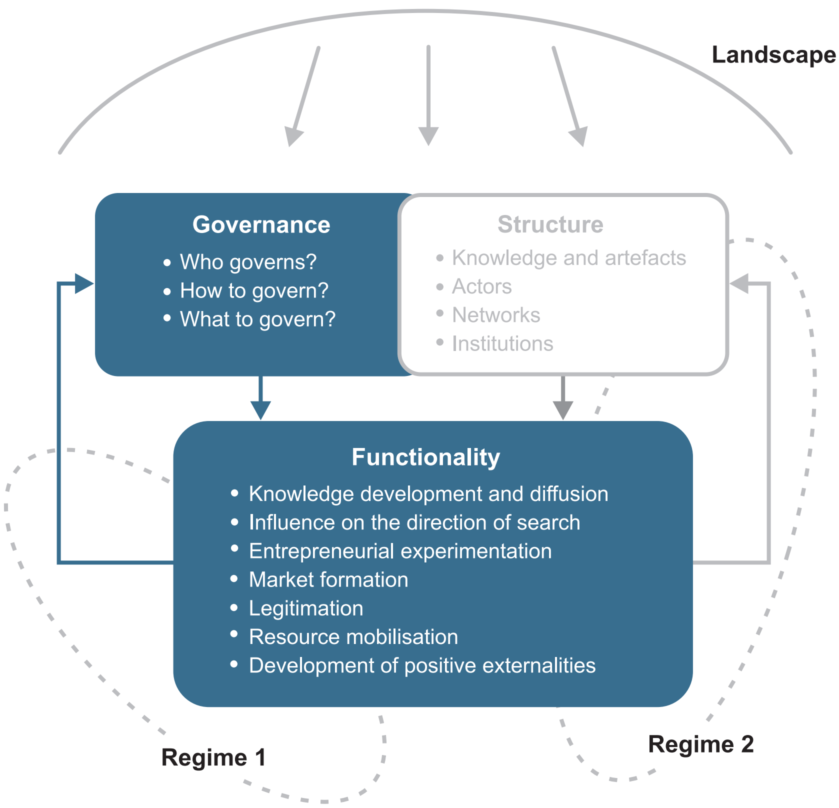

Figure 2: Schematic presentation of the theoretical framework (Hillman et al., 2011)

The system involves numerous feedback loops, as indicated by the recurring arrows.

number of feedback loops. We further assume that the influence of governance arrangements will be quite different depending on external factors on various levels (Figure 2). First, there is the overarching level of societal developments (e.g., the general climate debate and the economic situation) largely unaffected by changes on lower levels (Rip and Kemp 1998; Geels 2002; Smith 2003). We suspect landscape factors to condition the governance arrangements' influence on functionality by creating (or reducing) opportunities for innovations. Second, regimes are the result of alignment of dominating rules in certain parts of the socio-technical system, providing for stability and focus on less radical changes (Markard and Truffer 2008). They do not determine the development but give direction for actions performed by the actors of the system. The degree of alignment between the TIS and adjacent regimes, such as overlapping actors and institutions, affects the intensity of regime resistance towards the TIS (Markard and Truffer 2008). This also applies to the alignment with other TISs, i.e., of other technologies and/or in other geographical entities.

The key processes depend on the structure and in turn change the structure. Thus, the aggregation of the key processes – the functionality of the TIS – indicates the potential for changes in structure. Most TIS studies measure functionality in a predominantly qualitative manner, captured through actors' perceptions of, e.g., knowledge supply and diffusion, uncertainties, bottlenecks, sufficiency of guidance, availability of resources, etc. (see, e.g., Bergek *et al.,* 2008a). However, as noted by Hillman *et al.* (2011), recent publications also propose some quantitative indicators.[10] In general, one may use both quantitative and qualitative data to estimate the status of each key process.

The theoretical framework makes possible a temporal analysis, that is, of changes in governance and changes in functionality, and we contextualise the relationship between these two through the influence of landscape factors, and the alignment with established regimes and other TISs (which also change over time). As a starting point, we use the analytical procedure presented by Hillman *et al.* (2011), which is slightly modified for the purpose of this report (Table 2).

Table 2: Procedure for applying the theoretical framework in this report

(modified, Hillman *et al.*, 2011)

- Identifying structural elements (for each period)
  - Landscape and industry dynamics
  - Biofuel governance and industry activities
  - Summary
- Tracing the key processes of the TIS
  - Indicators of the process
  - Assessment of the process
  - Influence of governance
- Assessing governance and overall functionality
  - Evaluation of overall functionality
  - Influence of governance
  - Influence of external factors

First, relevant landscape factors, regimes and other TISs are introduced, primarily concerning global societal trends and industry dynamics, followed by a description of Swedish governance arrangements and industry activities related to the studied TIS. Second, the key processes of the TIS are traced. For each process, relevant indicators are selected and motivated in relation to the specific case: both qualitative and quantitative indicators are useful.[11] Then the status of each process over time is mapped with help from publications and interviews (see below). Particularly, the relative contribution to the processes by each governance arrangement is estimated. Such causal attribution need to be confirmed through interviews and evaluation reports, while it also follows from the quantitative indicators; an arrangement contribute, e.g., a number of publications (*Knowledge Development and Diffusion*), a certain amount of money (*Resource Mobilisation*), or an increased market size (*Market Formation*). Finally, the overall functionality and the influence of governance on functionality is assessed.

10 These indicators were collected from Bergek et al. (2008a; 2008b), Hekkert et al. (2007), Suurs (2009), and van Alphen et al. (2009). Indicators for the seventh process – Development of Positive Externalities – are not included due to its dependence on feedback loops from other processes (see also Bergek *et al*., 2008b). Also, this process is not used by Hekkert et al. (2007).

11 The former type follows from the description of each process (Table 1), while examples of the latter are presented in Tables 3-6 and 8-9.

The overall functionality is evaluated based on the aggregation of the key processes. Taking their relative influence into account, patterns in how various arrangements affected key processes are sought.[12] Finally, any identified patterns should be put in relation to prevailing landscape factors, and alignment between the TIS structure and regimes and other TISs.

We used different approaches to organise and interpret data when implementing the framework. The predominant methodology for the synthesis was qualitative, involving interpretations of complex social phenomena, based on the in-depth understanding of processes and details (George and Bennett 2004). A thorough review of documents issued by governmental organisations, firms and NGOs (e.g., policy documents, and project, annual, and evaluation reports) was central in recording the details. This was complemented with a wide sample of interviews with key persons, who confirmed and added activities and governance arrangements, and pointed out relevant documents. Most importantly, the interviews were crucial to develop our understanding of the processes. We carefully selected respondents to cover the development throughout the whole epoch, and made sure all different types of actors in the value chain were represented. This entailed 25 interviews during 2004-2009 with people from governmental ministries and agencies, interest organisations, cities/municipalities, farmers' organisations, technology and strategy consultancy, technology firms, fuel distributors, and vehicle manufacturers (see Appendix).

12 If the number of governance arrangements is large, they can be categorised based on the dimensions presented in the Appendix before this analytical step is taken.

2 THE INNOVATION SYSTEM FOR BIOFUELS IN SWEDEN

The vehicle industry and related suppliers are of significant importance for the Swedish economy, both on national and regional levels. There are four major road vehicle manufacturers in Sweden: Volvo Cars and Saab Automobile produce cars, while Volvo and Scania are into trucks and buses.[13] During part of the studied epoch, part of these companies was under foreign ownership, though their main activities were still located to Sweden. In 1989, Saab Automobile was partly sold to General Motors, which affected what activities should be kept within the company and what should be left to other parts of the group.

As in many other countries, the work with alternative fuels in Sweden started after the first international oil crisis in 1973. The government and the vehicle manufacturers built up organisations for R&D of synthetic fuels. These were to be produced primarily from fossil resources, but some studies on biomass were conducted, as well. In addition, various blends of methanol and petrol were tested in cars and heavy vehicles. The activities continued through the second oil crisis in 1979 until the mid-1980s when oil substitution in the transport sector became less prioritised. Some of the individuals, networks and organisations lived on in other sectors, and returned to the field of vehicle fuels in the 1990s (Sandén and Jonasson 2005).

The idea of using ethanol instead of, or blended into petrol can be traced back to the first half of the 20th century and strategic concerns in times of war. In addition, ethanol was of importance as a feedstock for the chemical industry. For these reasons, the supply of ethanol from a sulphite pulp mill in Örnsköldsvik was financially supported by the government in the early 1980s. In addition, the Foundation for Swedish Ethanol Development (SSEU) was initiated by the county, farmers, and companies and municipalities around the mill, to promote and develop the use of ethanol in vehicles. Later the company Sekab (Swedish Ethanol Chemistry Ltd) was formed, supplying ethanol and related chemicals since then. In the mid 1980s, two city buses in Örnsköldsvik were rebuilt by SSEU and run on ethanol fuel from Sekab.

In the early 1980s, the farmers' organisation got funding for a demonstration plant for production of ethanol from grains. The plant was in operation for a few years, and the ethanol was sold to the cooperative oil distributor OK, and was blended into petrol in mid-Sweden. Not much happened after the project, but the farmers' organisation continued their planning and lobbying for economic incentives to build a full scale plant. The production of ethanol for use in low-level blends was seen as a way to market surplus grains. Parallel to the more visible ethanol activities, R&D of cellulosic ethanol was carried out at some universities since around 1980.

Already before 1990, biogas was produced from sewage sludge and landfill sites by some municipalities and it was increasingly used for local energy supply. There were also some smaller farm units for production of biogas from animal manure emerging at this time.

Regardless of the mentioned activities, and a few studies and reports, it was not until around 1990 that alternative fuels for road vehicles seriously re-entered the governance agenda, and then with a primary focus on fuels produced from biomass (i.e., biofuels). In the coming sub-sections (2.1 - 2.3) we describe the TIS for biofuels in Sweden and its context from 1990 to 2010. This epoch is divided into three shorter periods, representing experimentation (1990-1996), the build-up of markets (1997-2003), and mass market formation (2004-2010) for first generation biofuels. For each period we discuss overarching landscape and industry dynamics, and then more specifically, biofuel governance and industry activities.

2.1 1990-1996: R&D AND EXPERIMENTATION

Landscape and industry dynamics

The severe problems with urban air quality were high on the agenda for policy makers around the world. The primary responses from the fuel and vehicle regimes were to improve fuel quality (both petrol and diesel) and introduce catalytic converters for petrol cars, but there was also an increase in activities related to alternative fuels.

In some countries, ethanol was already used as a vehicle fuel. Brazil, the largest producer of sugar cane in the world, had an ethanol programme since 1975, motivated by the increasing cost for imported oil. Many multinational vehicle manufacturers developed vehicles dedicated to almost pure ethanol for the Brazilian market, and up to 22 per cent ethanol was

13 The Volvo Group is also a producer of various other types of vehicles and vehicle technology.

blended into conventional petrol, requiring only minor adjustment of vehicles (Goldemberg and Macedo 1994). Also in the US, 10 per cent ethanol (or an ethanol based additive) was blended into petrol to reduce carbon monoxide emissions in sensitive areas, to reduce dependence on imported oil, and to favour the domestic agriculture.

In the US, a credit for alternative fuel vehicles in the CAFE (Corporate Average Fuel Economy) standard began to have an effect on the production of flexifuel vehicles (Department of Transportation *et al.,* 2002). A few thousand Ford Taurus flexifuel cars were out on the roads at the end of the period, offering the possibility to run on any mixture of E85, M85 and petrol. However, the credit was related to the vehicles produced and not to the fuel used, and most of those cars actually used petrol.

Natural gas vehicles and related fuels were marketed in several countries as a way to reduce oil dependence and local emissions of air pollutants. In Sweden, a number of natural gas buses were introduced in Malmö and Göteborg and at the end of the period the first bi-fuel cars were delivered by Volvo. These vehicles could in principle run on biogas instead of fossil natural gas. A natural gas pipeline from Denmark reached south-west Sweden, but political resistance and postponements of further expansions favoured biogas investments (Sandén and Jonasson 2005).

Concerns for global warming and climate change were on the rise. At the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro 1992, the Climate Convention was approved, which prepared the ground for the Kyoto Protocol in 1997 with targets for the reduction of greenhouse gas emissions. Global warming was not the main driving force for biofuels at the time, but the knowledge was likely contributing to the focus on non-fossil alternative fuels in Sweden. Also, there was an increasing commitment to environmental issues in many Swedish municipalities, partly as a result of the Agenda 21 'Programme of Action' published after the Rio conference. Finally, the oil price remained relatively stable during most of the 1990s and did not cause any urgent action from the actors of the Swedish TIS.

Biofuel governance and industry activities

During this period, a 'three party agreement' on the energy policy (Swedish Ministry of Industry 1991) prepared the ground for two biofuel R&D programmes funded by the Agency for Industry and Technology Development (Nutek) and the Communication Research Board (KFB), respectively: the Ethanol Development Programme on cellulosic ethanol, and the Biofuels Programme, a demonstration programme on ethanol in heavy vehicles. The three party agreement also opened up for ethanol from wheat, but this did not result in a plant until 2001 (see section 2.2).

An Ethanol Bus project in Stockholm in the early 1990s entailed 30 ethanol buses operated by the regional Stockholm Public Transport. Working with information and lobby activities, the ethanol foundation SSEU was involved in this project, and also in the Biofuels Programme. At the end of the period SSEU performed a demonstration of flexifuel cars in two steps: in 1994, three Ford Taurus were imported from the US, and then 50 more were imported and leased out (Carstedt 2005). There was an agreement with the fuel distributor OK to put up pumps for E85. Until 1997, about 300 Ford Taurus were sold and many E85 pumps were installed. The small volumes of ethanol used for the buses and cars were provided by Sekab. Thus, the network centred around Örnsköldsvik played an important role for the development of ethanol in this period.

In Linköping, biogas upgrading and buses were introduced by local authorities and the municipal energy company. Due to the interest in a number of cities, biogas projects were included in the national Biofuels programme, primarily intended for ethanol (Månsson *et al.,* 1998). In addition, both municipal and private companies involved in such experimentation contributed human and financial capital.

In 1994, a general exemption from fuel taxes (energy and CO_2 taxes) was implemented for biogas. At the same time, there was an opening for tax exemptions for pilot projects concerning biofuels and other alternative transport fuels (Swedish Government 2010a).

In this period, pure rapeseed oil for vehicle use was produced by farmers, and at some locations small scale production units for RME (rapeseed methyl ester) was in operation. It was seen as a way for farmers to profile themselves environmentally. In 1993 an estimated 2000 tons of RME was used as a transport fuel (NUTEK 1994), but quality problems were common (Herland 2005). The production of oil crops radically decreased after the EU entrance in 1995, as until then there had been national support for domestic production (Herland 2009).

At the end of the period, a governmental Commission on Alternative Transport Fuels published its results on environmental classes and taxation of fuels.

From an environmental viewpoint, the biofuels biogas, ethanol and methanol was ranked top three, but more investigation was recommended (Alternativbränsleutredningen 1996). Shortly after this, the Commission on Communications presented a strategy for ethanol introduction (Kommunikationskommittén 1997), which was followed by more investigation (Brandel 1997), but no concrete plans were implemented (Brandel 2005).

Summary of the period

Throughout the first period, there was a recurring governance focus on ethanol. Biogas entered governance, but most other alternatives were non-existent. A number of circumstances may explain this picture. First of all, the ethanol focus was in accordance with the interest of both the Foundation for Swedish Ethanol Development (SSEU), who generally promoted ethanol use in vehicles, and the farmers, who wanted to produce ethanol from surplus grains. Second, ethanol vehicles and production of ethanol from wood had not been tested in large programmes before.[14] Third, biogas as a transport fuel was only brought up by local initiatives to become part of national governance. Finally, concerning rapeseed based fuels; they were produced and used on a small scale, not officially sanctioned due to quality and emission doubts at the time.

2.2 1997-2003: R&D AND BUILD-UP OF MARKETS

Landscape and industry dynamics

At some locations the problems with urban air quality were getting under control, while the climate change debate gained in intensity among some groups after the adoption of the Kyoto Protocol in 1997. Through the protocol, several countries committed to reduce their emissions of some important greenhouse gases between 1990 and 2012. Since the early 2000s, biofuels were high on the political agenda in Sweden and in the EU, and environmental and agricultural interests were important parts of the political debate. In addition, a steeper increase in oil price began around 1999.

In the US, there was a dramatic increase in production of flexifuel cars and light trucks due to the CAFÉ credit, but most of them were fuelled by petrol. In 2003, flexifuel vehicles were introduced on a wide front also in Brazil. Furthermore, production and use of various biodiesel blends increased during this period, particularly in Germany. Saab was fully acquired by GM in 1998, and Volvo Cars was bought by Ford in 1999. These acquirements by large US vehicle manufacturers influenced what kind of R&D of alternative power trains that should be pursued by the Swedish brands.

Biofuel governance and industry activities

In this period, the early markets for biofuels and clean vehicles were stimulated all over Sweden. Ethanol or biogas buses were purchased by municipal public transport companies in several cities, and, biogas production, upgrading and distribution were mainly performed by municipal companies. Procurement of clean cars by municipal and regional authorities and their companies was a widespread arrangement, and to gather a critical mass of customers, there was cooperation between regions, e.g., in a flexifuel car procurement resulting in the release of the first flexifuel car in Sweden – Ford Focus – and the installation of several E85 pumps. Clean car organisations formed by municipal actors in the larger cities were important organisers of such procurements, and they were also central providers of information. Several municipalities applied policies in favour of clean cars, e.g. for mobility services, taxi and rental cars. There were also local subsidies for clean car purchase, and some clean car sharing projects. In Gothenburg, parking fee subsidies for clean cars were introduced. These arrangements were typically driven by municipal authorities and companies, while additional funding was provided by a national investment programme (LIP) and various EU programmes, in which the larger cities participated.

Markets were developing differently for the alternative technologies. Pure RME was first included in some of the clean car arrangements, but was later abandoned for reasons of local emissions (Sandén and Jonasson 2005). In the early 2000s, ethanol was temporarily imported from Southern Europe, where it was produced from excess wine, but later the import from Brazil came to dominate. The pulp mill in Örnsköldsvik supplied smaller volumes of ethanol, and a domestic plant for wheat ethanol was built in Norrköping by agricultural stakeholders. It started production in 2001, still too small to supply the Swedish market: Fuel ethanol was used for low-level blending into petrol (E5), as well as for E85 in flexifuel cars since around year 2000, and for a fuel containing 95 per cent ethanol (ED95) used for heavy vehicles, mainly city buses produced

14 Synthetic fuels, however, had been tested in the 1970s and early 1980s, then primarily with fossil resources, but any activities were now focused on heat and electricity production (Sandén and Jonasson 2005).

by the Swedish manufacturer Scania. Concerning biogas, various actors were involved in its production and distribution, of which municipal companies were central. Biogas was sometimes sold in mixtures with natural gas, then marketed as 'Vehicle Gas'. Still, the selection of methane cars was limited.

A government commission on Biogas as a Vehicle Fuel (Biogasutredningen 1998) was followed by a cooperation programme called Biogas in Vehicles, which involved the Swedish Energy Agency and a large range of biogas stakeholders (Rietz 2005). The research on cellulosic ethanol was continued. At the end of the period, an R&D programme for synthetic fuels (called FALT) started up, and R&D of DME produced through gasification of black liquor was supported, with the technology developer Chemrec as the main stakeholder.[15] R&D was mostly funded by the Energy Agency, and in the case of black liquor also by private financiers.

Since 1998, the Swedish Road Administration (SRA) implemented a policy for its rental and purchase of vehicles with focus on safety and environment (Nilsson 2009a). The policy was regularly updated with stricter requirements. A few years later, a strategy document was released by SRA and three other governmental agencies, who recommended R&D of synthetic fuels from biomass gasification and demonstration of cellulosic ethanol, while also recognizing ongoing market developments for first generation biofuels (Skogö *et al.,* 2002; Eriksson *et al.,* 2003). About the same time, a commission communication on alternative fuels was released at the EU level (EU 2001). This was followed by a Biofuels Directive (EU 2003), in which targets for the introduction of biofuels in the EU member states were set to 2 per cent by 2005 and 5.75 per cent by 2010.

On the national government level, for clean cars, the fringe benefit tax for private persons using their company car off duty was reduced.[16] The tax exemptions for biogas and pilot projects were continued. The public-private SSEU was renamed BAFF (BioAlcohol Fuel Foundation), and continued lobbying for ethanol fuels and vehicles. Concerning biogas, a branch development project called Biogas West was initiated in 2001 by authorities and companies in the west of Sweden (Ahlbäck 2003).

15 The R&D of black liquor gasification followed from private activities and a government programme for support of electricity from biomass (FABEL).

16 The total number of company car users was in 2003 about 200 000 (Sandebring 2004b).

Summary of the period

Significant for this period was the increasing governance, at various levels, directed at the market for clean vehicles in general. In principle, any generation of biofuels could be used in such cars, but only first generation ones were available; out of these, biogas and particularly ethanol benefited from such arrangements. Still, imported ethanol and flexifuel cars were largely competitive with only fuel tax exemptions. The selection of bi-fuel cars was limited, though the market was expanded due to the use of natural gas in some cities. In general, many actors were clearly willing to make use of various economic incentives and invest both time and money in biofuel development. Until the end of the period, arrangements that specifically addressed synthetic fuels were lacking, despite a generally positive view of gasification, as communicated by researchers and analysts.

2.3 2004-2010: PILOT PLANTS AND MASS MARKET FORMATION

Landscape and industry dynamics

Environmental issues were high on the national policy agenda, and in the research bill from 2005 sustainable development and environmental technology were prioritised fields (Swedish Ministry of Education and Culture 2005). In the EU, an emission trading scheme for selected greenhouse gases went into force, and it covered a range of stationary installations, such as industries and power plants. Though emissions from road transport were not formally included, the scheme generally influenced organisations to calculate the potential cost of their greenhouse gas emissions.

The climate change debate radically increased intensity among the public due to a number of events taking place in 2005-2007 (Nilsson 2009b). First, the hurricane Katrina hit the south-east of North America in 2005 and reminded people of the power of climate events.[17] Second, former US vice president Al Gore released a film in 2006 based on his speech about global warming – An inconvenient truth – that got massive attention around the world. Third, that same year, economist Nicholas Stern released a report for the British Government on the economics of climate change, which strengthened the economic arguments to deal with global warming. Fourth, the Intergovernmental Panel on Climate Change (IPCC) released its report Climate

17 It could not be stated, though, that a single event like Katrina or its severe effects can be referred to global warming.

Change 2007 with the science behind climate change. As pointed out by a representative from the Ministry of the Environment, these four events represented a mix of natural phenomena, politics, money, and science (Nilsson 2009b). On top of these events, the oil price rose sharply since 2005 and a debate about peak oil took entered the scene.[18]

Ethanol and biodiesel production from various raw materials was growing in many countries around the world, particularly in Brazil and US. Low-level blends were on the rise, but still few vehicles worldwide were running on high-level blends. After their introduction in 2003, flexifuel vehicles increased rapidly in Brazil, which entailed that most multinational vehicle manufacturers sold such vehicles on that specific market. A low import tax on Brazilian ethanol and a favourable currency made E85 relatively cheap in Sweden (Kärrberg 2009). However, despite various governance arrangements, the economic benefit of biofuels was shifting with the price of oil.

In this period, the share of diesel cars in the sales of new cars increased in Sweden, while the share of petrol fuelled cars decreased. This was partly a result of the perceived environmental advantage and changed regulation of diesel vehicles, due to high fuel efficiency and newly introduced particle filters. The sales of diesel and petrol fuels changed accordingly, and the decreased sales of petrol – containing five per cent ethanol – influenced the total use of ethanol negatively.

The debate on sustainability and climate change was broadened during the period, to involve also aspects such as working conditions, food prices and land use. A direct effect on the biofuels TIS – a more critical stand towards particularly ethanol and biodiesel – was seen from around 2007-2008. This favoured efficiency increase and electrification through hybrids, plug-in hybrids, and electric vehicles, at the expense of alternative fuels.

The economic recession that surfaced in 2008 led to reduced demand and a radical decrease in the price of oil. In particular, this affected the sales of E85 in Sweden negatively. Furthermore, the combination of the recession and the low prices of fossil fuels made many investments run out of steam. Many ethanol plants around the world were running on reduced capacity, or were temporarily shut down (Herland 2009). The recession was largely intertwined with a financial crisis and a crisis for the automobile industry that set off a process where Volvo Cars and Saab Automobile were sold by their US owners, to Chinese Geely and Dutch Spyker Cars. This potentially made Volvo and Saab more independent, though any clear effects on biofuels development were yet not seen.

In the last years of the period, there was again a steady increase in the price of oil, and the general expectation among Swedish regime actors was that the oil price would increase in the coming decades, due to limited supply.

Biofuel governance and industry activities

Early in this period, the actual state of biofuels development and a discussion of selected governance arrangements were presented by a Commission on Renewable Transport Fuels (Sandebring 2004b; a). The national targets compliant with the Biofuels Directive were set to 3 per cent for 2005 and 5.75 per cent for 2010, respectively (Swedish Ministry of Sustainable Development 2006b). The actual share reached for 2005 was 2.23 per cent, and only Germany had a higher level in the EU (EU 2007). At the end of 2010, Sweden had reached a share of 5.6 per cent (Swedish Transport Administration 2011). The dominating part of the biofuel volume was ethanol; it was used for blending into petrol (1.6 per cent in 2010), in E85 (1.2 per cent) and in bus fuel (0.2 per cent). Sekab was the dominating importer of ethanol in this period, but an increasing share of the import was made by fuel distributors themselves.[19] Most ethanol was imported from Brazil, and the rest from Europe; the proportions were decided by present price relations and contracts. The pulp mill in Örnsköldsvik still supplied a limited amount, and the wheat ethanol plant in Norrköping expanded in 2009.

The number of flexifuel cars increased dramatically during the period. First, in 2005 the Swedish manufacturers Saab and Volvo followed Ford in delivering flexifuel cars on the Swedish market. Then, most other manufacturers introduced flexifuel cars on the Swedish market with only small price additions – 5 000 to 12 000 SEK – compared to petrol fuelled models (BEST 2009). Biogas upgrading to 'vehicle quality' continuously increased, and private companies became to a higher degree engaged in distribution. The selection and sales of bi-fuel cars increased only slowly.

18 'Peak oil' refers to the point in time when increased demand cannot be met by increased production, thus resulting in a rising price.

19 At the time of the economic recession (around 2008) Sekab was restructured at the request of its owners (see below).

The price addition for bi-fuel cars, as compared to petrol and diesel cars, was up to 47 000 SEK (BEST 2009).

Early in the period the Swedish diesel standard was adjusted so that the RME share in conventional diesel could be raised from 2 to 5 per cent (Swedish Ministry of Sustainable Development 2006a). This dramatically increased the market for RME, which by some actors had been considered too small to exploit (Herland 2005). Large scale RME plants were built by various commercial actors: The fuel was mainly used for low-level blends with conventional diesel. There were also some higher-level blends and pure RME used in conventional or slightly adjusted diesel vehicles, but volumes were limited. Towards the end of the period, the EU RES directive (see below) opened up for further increasing the share of biofuels in conventional fuels; from 5 to 7 per cent FAME in diesel, and from 5 to 10 per cent ethanol in petrol (EU 2009a).

The market for commercially available biofuels and clean cars were still in focus. In this context, most arrangements from the previous period were continued, while many were added. It became legally sanctioned that state actors should purchase a certain share of clean cars, a share that was regularly increased over the years (Swedish Government 2004). Clean cars were exempted from congestion tax in Stockholm, a CO_2 based vehicle tax was introduced (Swedish Ministry of Finance 2005), and there was a new law that forced filling stations with supplies above a certain level to provide at least one renewable fuel (Swedish Ministry of Sustainable Development 2005). The last-mentioned mainly resulted in ethanol pumps, though additional grants were available for biogas installations. In 2007, a subsidy for private persons buying any clean car was introduced. It also became legally accepted to convert a conventional vehicle to a clean vehicle and gain access to the incentives offered. Regarding heavy vehicles, the Ethanol Bus (and Truck) Initiative was formed by Sekab and regional actors in Stockholm early in the period to gather a critical mass of customers for procurement of ethanol buses, and later also ethanol trucks.

Local/regional companies, particularly municipal energy companies and large customers of fuels and vehicles, funded market directed arrangements. Also during this period, EU programmes contributed funds for local/regional market arrangements, and LIP was replaced by a new climate-focused national investment programme called Klimp, which in the field of biofuels and clean cars prioritized biogas projects.

In 2006, an 'EU Strategy for Biofuels' was presented by the European Commission (EU 2006), which prepared the ground for an update of the Biofuels Directive, which was finally released in the RES (Renewable Energy Sources) Directive in 2009 (EU 2009a). This contained new ambitious biofuels targets that were questioned by many stakeholders as they were not connected to a system for sustainability certification. Such a connection finally came into force at the end of 2010 (EU 2010). In addition, there was a small advantage for manufacturers of flexifuel cars in the EU CO_2 emission performance standards for new cars (EU 2009b). Discussions among various stakeholders at the EU level were taking place, e.g., within the European Biofuels Technology Platform.

Numerous R&D programmes were running. The FALT gasification programme continued until 2006, and a pilot plant for biomass gasification was in operation within the ChrisGas project until 2010. A pilot plant for cellulosic ethanol was built in Örnsköldsvik, owned by universities in the region and operated by Sekab. In 2005, Sekab was bought by a regional consortium in the north-east, constituted by a number of municipal energy companies, aiming to contribute to technology development and keep activities in the region. Furthermore, a pilot process for an ethanol energy combine was tested in Sveg – by a company owned by Chinese stakeholders, the municipality and a regional bioenergy company. However, still in 2010, no significant volumes of cellulosic ethanol had been produced in Sweden.

The R&D of black liquor gasification and DME production was continued, with large companies like Volvo and state-owned Vattenfall supporting the Chemrec technology. Volvo also showed an increased commitment to develop heavy vehicles for DME and public vehicle tests were planned. Late in the period, upscaling of a black liquor gasification concept was planned to Örnsköldsvik. Concurrently, a plant for biomass gasification and biogas production was prepared in Gothenburg within the GoBiGas project, driven by the energy companies E.ON and the municipal Göteborg Energi. The Energy Agency was still crucial for R&D funding, and EU programmes for R&D and regional development were increasingly turned to. For some years, there were also private discussions of a methanol plant in mid-Sweden, called VärmlandsMetanol.

Throughout the period, a number of information focused EU projects were carried out, such as Trendsetter and BEST, that engaged local/regional actors (e.g., the clean car organisations). There were also system studies at the EU level with researchers and various stakeholders from many countries, including Sweden. An influential example is the series of well-to-wheels analyses developed since 2003 by the European Commission Joint Research Centre (JRC) in cooperation with the European vehicle and fuel company associations EUCAR and CONCAWE. These analyses aimed to reach some kind of consensus among different stakeholders on the performance and prospective for all alternative fuels.

Until now, each city had its own definition of clean vehicles that stated which vehicles that could take advantage of local incentives. This situation partly changed as a national definition of clean cars was implemented, which included all cars equipped to run on alternative fuels (except LPG) with fuel consumption below a certain level (Swedish Government 2004; 2005).[20]

Organisations from the previous period were still active and successful in lobbying for biofuels and clean cars. For example, the domestic car manufacturer Saab engaged BAFF for an information campaign at the release of Saab BioPower (flexifuel car), which defied the prejudice that clean cars offered less performance than conventional cars. Furthermore, as an answer to the debate about the sustainability of biofuels, a number of certification schemes were developed. Most importantly, there was an ongoing process for the development of sustainability criteria in relation to biofuel policies at the EU level, and the first guidelines were presented in the RES directive (EU 2009a). Meanwhile, the ethanol company Sekab released its Verified Sustainable Ethanol, and FordonsGas had its mixture of natural gas and biogas labelled with the Nordic Ecolabel 'the Swan'.

The fuel distributor OKQ8's plans for marketing the Finnish Neste biodiesel (NExBTL) produced primarily through hydrogenisation of imported palm oil were cancelled due to an arising debate on the sustainability of the raw material. Since 2010, there were small volumes of biodiesel produced by Swedish Sunpine through hydrogenisation of crude tall oil, i.e., a by-product from the pulp and paper industry.

At the end of the period, the Energy Agency developed a national biogas strategy (Swedish Energy Agency 2010b) that was criticised for its too low ambitions regarding the expansion of biogas. Furthermore, some local subsidies and exemptions were discontinued, and the clean car premium was replaced by a five-year vehicle tax exemption. In addition, though higher blends were allowed by the EU RES directive, it was decided that the Swedish tax exemptions should only be applicable up to respectively 5 and 6.5 per cent for biodiesel and ethanol, and for high-level blends (Swedish Government 2010b). The reasons for these weaker incentives were mainly related to increasing costs with larger volumes of biofuels and clean cars.

Summary of the period

The EU Biofuels Directive from the previous period and the targets set were influential throughout this period. Also, an intensified debate on climate change and peak oil strengthened all kinds of technology for renewable energy. Various biofuel alternatives were addressed by governance, but first generation ethanol dominated the market and the general interest in times of intense climate debate. This changed slightly as ethanol and biodiesel were questioned from a sustainability perspective; at the same time, energy efficiency and future electrification of vehicles became popular. Still, the allowed blending levels were increased to 10 per cent ethanol in petrol and 7 per cent biodiesel in conventional diesel.

Sustainability criteria were developed by various organisations to steer towards increasingly better biofuels. Except from this, the market-directed governance arrangements were typically relevant for first generation biofuels only. Concerning second generation biofuels, a number of pilot plants for synthetic fuels and cellulosic ethanol were in focus. At the end of the period, two large projects around second generation biogas and black liquor/DME were pointed out by the Swedish Energy Agency as its two major biofuels investments.

20 In addition, petrol and diesel cars with low emissions of CO_2 (e.g. hybrids) and electric cars with limited energy use were included.

3 INNOVATION SYSTEM FUNCTIONALITY AND GOVERNANCE

In line with the framework, system performance is evaluated through the study of key processes, and the effectiveness of governance arrangements refers to their impact on those processes. In this section we analyse the functionality of the TIS for biofuels in Sweden, based on the progress of the key processes, and we also estimate to what extent these processes were influenced by the governance arrangements described in the previous section. In this context, only the most influential arrangements are discussed, while a complete list is found in the Appendix. The analysis is structured according to the key processes. For each process, the used indicators are presented and motivated and the assessment of the process is presented. From this, the contribution of governance to each process is estimated and summarised. The section ends with an aggregated analysis of the overall functionality and how this was influenced by governance arrangements and external factors (3.8).

3.1 KNOWLEDGE DEVELOPMENT AND DIFFUSION

Indicators of the key process

The process of *Knowledge Development and Diffusion* is described as 'the generation of breadth and depth of the knowledge base of the TIS, and the diffusion and combination of knowledge' (Table 1). The field of biofuels embraces various types of knowledge in many different domains, and we are in this report interested in two of the main types. First, there is technical knowledge concerning production of vehicles and fuels, and distribution of fuels. Second, consumer and user knowledge is built up as biofuel vehicles are considered realistic alternatives to petrol and diesel ones, and as they are increasingly used by different kinds of users. This second kind of knowledge is not developed when biofuels are blended into petrol or diesel.

There are a number of indicators that can be used to help estimate *Knowledge Development and Diffusion* for the two types of knowledge (Table 3). Here we focus on the number and size of R&D, pilot and demonstration initiatives, official private activities, and joint organisations and conferences. Due to the large number of activities and the time limitations of the study, we limit our investigation to larger programmes or equivalent arrangements, typically involving large resources for many projects.[21] In the present case, all such programmes analysed were part of governance. In addition, we include the internal development work performed by private companies that were revealed in interviews, and that typically resulted in concept vehicles and market releases. The diffusion of knowledge is indicated by conferences and organisations active in informative activities. The indicators used mainly capture technical knowledge; user knowledge is instead for the most part an implicit result of *Market Formation*. Finally, due to the limited time available for the study, we refrain from performing strictly quantitative analyses of, e.g., patents and articles.

21 Due to the large number of initiatives, it has not been possible to perform an analysis on project level.

Table 3: Indicators for assessing the key process Knowledge Development and Diffusion

(Hillman *et al.*, 2011)

- Number of publications and citations, degree of variety
- Number and size (money, number of people) of R&D, pilot and demonstration projects, degree of variety
- Number of patents, assessments and studies
- Number of conferences and workshops
- Volume of co-patenting, co-publishing, number of alliances between actors, joint ventures, platforms/ branch organisations

Assessment of the process

On an overall level, knowledge development was characterized by a number of R&D, pilot and demonstration programmes with a multitude of actors involved, such as the Energy Agency, researchers, consultants, private companies and municipal actors. There was a scale from strictly defined programmes with respect to the actors and activities involved, to those with a more open approach, where actors were invited to participate within a certain field.

Support for development of cellulosic ethanol was present throughout the studied epoch, with R&D carried out at universities, and since 2004 also at a pilot plant. However, there was no decision on upscaling to build a demonstration plant. Regarding synthetic fuels, these were developed within three different tracks. First, development of black liquor gasification and subsequent production of DME, dating back to activities at Kvaerner in the 1990s, was transferred to and driven by Chemrec. In 2010-2011 there were concrete plans (and funds) for upscaling to a demonstration plant. Second, since 2003-2004, R&D of biomass gasification was performed within FALT (Research Programme on Alternative Transport Fuels) and the production of synthesis gas was tested in a pilot plant for the Chrisgas project. At the end of the epoch, a concept for production of biogas through biomass gasification was developed and a plant was planned to be built in Göteborg. In addition to the larger programmes and company activities, researchers, consultants, companies, and NGOs continuously engaged in studies and produced reports on the technical and environmental properties of various alternatives. A series of studies of particular importance was the JRC/EUCAR/CONCAWE well-to-wheels analyses released since 2003.

Knowledge regarding the use of ethanol in vehicles was developed in the 1990s within the Biofuels Programme for heavy vehicles, and in relation to the flexifuel car demonstration. Bus development at Scania and Volvo and early investments in buses and fuel distribution by municipal companies contributed further to knowledge development. Scania decided to cancel production of ethanol buses in 2004 (Rydén 2005), but soon after the company took up the development of ethanol engines for buses and trucks, of which the first was introduced in 2007 (Rydén 2009).

Producer and consumer knowledge related to fuels and cars was primarily gained when a larger number of users were included in clean car procurements that covered both flexifuel and bi-fuel cars (see also *Market Formation).* A number of test vehicles had been produced within Volvo (Cars) and Saab Automobile already in the early 1990s and Volvo started to sell bi-fuel cars in 1996, but it was not until 2005 that the two manufacturers released their first flexifuel cars. In 2006, Saab showed a concept hybrid electric flexifuel car that could run on pure ethanol (E100). That same year Volvo Cars demonstrated a 'multi-fuel' concept car that with two fuel tanks: one for 'hythane', biogas or natural gas, and one for E85 or petrol.[22] This showed that the company had the knowledge to develop cars for different biofuels. A corresponding demonstration was made by the Volvo Group in 2007, when seven trucks dedicated to different alternative fuels or fuel combinations were displayed, including biodiesel, biogas, DME, ethanol, synthetic diesel, and hydrogen.

There was a range of activities that particularly favoured the *diffusion* of knowledge. A number of government commissions treated most known alternatives to summarize the state of technology development, prospects for the future, and policy issues. The commission reports typically did not produce any new knowledge but functioned as some kind of common reference for policy-makers and various stakeholders.

Various organisations of different type played a role for knowledge diffusion. Dealing with various kinds of clean vehicles, clean car organisations were established in several cities since the 1990s. Also, the Green Motorists NGO was founded in 1994, and had an increasing influence on clean car information in general. More specific then were SSEU/BAFF, active during the whole epoch in the field of ethanol, and Biogas West that worked with biogas in the south-west since 2001.[23] Particularly the clean car organisations in the larger cities participated in some EU projects aimed at spreading information on biofuels and related issues. Regularly, there were conferences arranged by the various organisations, typically in cooperation with municipalities and regions.

Summing up, it can be said that *Knowledge Development and Diffusion* was progressing over time, and that most alternative biofuels were included in the process. Of course, more activities could have resulted in a more advanced state of second generation technologies at the end of the epoch.

Influence of governance

This process was largely dominated by governance in various forms, with the main exception that market introduction of vehicles and fuels brought in knowledge among producers, distributors and users. The total annual volume of public money for *Knowledge Development and Diffusion* is not estimated in this report, but there seemed to be a development towards larger and more specific R&D investments, including also EU programmes. In the first period, there was ethanol R&D and vehicle demonstration, and some pioneering biofuel projects by SSEU and local/regional actors, e.g., bus and flexifuel car demonstrations. In the second period,

22 In this case, hythane was to be made up by 10 per cent hydrogen and 90 per cent methane (biogas or natural gas).

23 Similar biogas organisations emerged around south Sweden in the years following.

R&D for ethanol continued, while synthetic fuels gained new support. Several biogas arrangements were initiated, such as a governmental commission, a cooperation programme and the branch development project Biogas West. Information was spread through clean car organisations (various alternatives) and BAFF (ethanol). At the start of the third period, knowledge was gathered and diffused through a governmental commission on renewable transport fuels. The period was characterized by investments in pilot plants for cellulosic ethanol, biomass gasification, and black liquor gasification, supported by the Energy Agency, various EU programmes, and private companies. The black liquor activities were due to upscaling at the end of the period, and a second generation biogas plant in Göteborg was supported.

Knowledge Development and Diffusion were emerging for all alternatives, but it can always be questioned if more governance was needed to speed up the process even more. Our interviewees pointed to knowledge gaps regarding policy issues. First, the Commission on Renewable Transport Fuels was expected to result in a proposal on how to proceed from the tax exemptions for biofuels; however, the lack of any concrete proposal rather 'resulted in a vacuum' in the policy process (Nilsson 2009b). Second, and more general, the representative from the Swedish society for Nature Conservation pointed out the problem that biofuel policies in Sweden were not evaluated (Nilsson 2009c). Such an evaluation was asked for in the parliament in 2007, but any results were first presented in 2011 (Swedish National Audit Office 2011). Furthermore, the large biofuel potential was expected from second generation biofuels that in the studied epoch only were produced in small volumes within R&D programmes. Commercial production of such fuels would probably be introduced earlier if R&D were supported even more in Sweden and in the EU.

3.2 INFLUENCE ON THE DIRECTION OF SEARCH

Indicators of the key process

The process of *Influence on the Direction of Search* is described as 'the existence of incentives and/or pressures for actors to enter the TIS, and to direct their activities towards certain parts of the TIS' (Table 1). The indicators used to assess this process are related to standards, regulations, targets/goals, project plans, visions, expectations, etc. (Table 4). These can be expressed by all kinds of actors of the TIS, but those that are supported by powerful actors or shared by many actors are likely the most influential ones.

Table 4: Indicators for assessing the key process Influence on the Direction of Search (Hillman *et al.*, 2011)

- Coherence and completeness of supportive standards, regulations and targets/goals (i.e. reduction of uncertainty)
- Believed growth potential, visions and expectations (e.g. from assessments)
- Official project plans, clear user demands (e.g. orders)

Assessment of the process

The main underlying factors behind *Influence on the Direction of Search*, which can be referred to the landscape, are made up by the concerns for urban air quality, increasing oil price, and global warming. Air quality was important for the whole period, while the oil price and global warming rose on the agenda since around year 2000 and 2005, respectively. More or less rapidly, these factors affected companies' strategies through expectations of market opportunities for cleaner and more fuel efficient vehicles, and for alternative fuels. The representative from Volvo Cars described the general focus on environment and climate as important for their marketing of methane and flexifuel cars (Kärrberg 2009).

Since around year 2000, the increasing oil price was very important to push the car industry (Lagerkrantz 2009), and already early it was used by BAFF as an argument for ethanol (Carstedt 2005) . Even if temporarily going down, the oil price was considered important in the long run; however, the fuel cost had always been important in the development of heavy vehicles (Klintbom 2009). According to the Volvo representative, the low price of oil for example in investment calculations for new establishments was the largest barrier for DME and biogas (Klintbom 2009).

The importance of the mentioned landscape factors was significantly strengthened through decisions and statements from the government, its ministries and agencies, and since 2001 from the EU. In addition to oil price and environmental issues, these instances communicated strong commitment to deal with energy security, international competition, and regional and agricultural development. Important national documents were, e.g., the three party agreement on the energy policy in 1991 that pointed towards ethanol, and the four agencies' introduction strategy in 2001-2002. At the EU level, several documents addressed biofuels development, such as the Commission Communication

(2001), the Biofuels Directive (2003), the Strategy for Biofuels (2006), and the RES Directive (2009).

The landscape debate on global warming and peak oil affected expectations and the believed growth potential of various alternatives very positively. In this debate, the studies mentioned in relation to *Knowledge Development and Diffusion* played an important role (section 3.1). However, the general Swedish interest for biofuels somewhat weakened around 2007-2008, as the debate came to include also the problems related to the production of raw materials for biofuels, particularly sugar cane in Brazil and palm oil in south-east Asia. The debate slowed down the development for biofuels (Nilsson 2009c), and the negative effect of the lower petrol price on E85 sales was probably amplified (Lagerkrantz 2009).

Influence of governance

Even though the underlying factors behind this process were often related to the landscape, governance arrangements were crucial to interpret and concretise such factors in relation to the studied case. The total number of arrangements in force that addressed *Influence on the Direction of Search* was increasing over time, which indicated that a more advanced TIS was potentially taking form (Figure 3). However, not all arrangements were equally important. In the first period, the three party agreement was a very influential arrangement, while two government commissions and national ethanol strategy had small effect on the direction of search. In the second period, public procurements early introduced into society a large number of vehicles, which were important symbols for the government's policies. The agencies' introduction strategy played a role for the balance between alternative technologies in that it particularly paid attention to second generation biofuels not seen on the roads, but considered key technologies in the long run. The EU documents released since 2001 were fundamental in the third period. However, problems to incorporate sustainability issues in EU policies and the parallel development of electrification technology contributed to that the relative importance of the policies was weakened. In Sweden, a national definition of clean cars was useful to clarify what should be considered environmentally friendly enough to benefit by coming incentives.

Though *Influence on the Direction of Search* was addressed through the years, uncertainty prevailed to some degree. At the beginning of the third period, the Swedish vehicle industry association stressed the lack of long term decisions regarding regulated and climate emissions from transports (Wallman 2004). Some years later, looking back, a representative from Volvo Car Corporation stated that the Swedish government kept their pace and that there were long term policies, good for the car industry (Kärrberg 2009). This was strongly confirmed by BAFF, who perceived consistent long term support from the government, which was not affected by temporary criticism (Rydén 2009). Also, on the regional level in Stockholm, the people working with the clean car organisation saw that the politicians in the city had been surprisingly unanimous in the first two periods (Hugosson and Sunnerstedt 2004). After the sustainability debate surfaced in 2007-2008, there was uncertainty regarding sustainability and future availability of biofuels (Lagerkrantz 2009); to some extent this was resolved with the implementation on the EU sustainability criteria at the end of 2010.

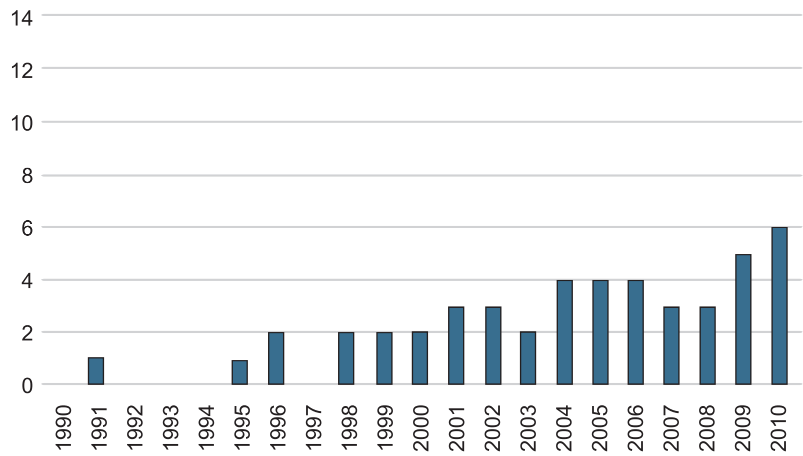

Figure 3: Number of governance arrangements in effect over the years, which addressed Influence on the Direction of Search as primary or secondary process

3.3 ENTREPRENEURIAL EXPERIMENTATION

Indicators of the key process

The process of *Entrepreneurial Experimentation* is described as 'the probing into new technologies and applications in an entrepreneurial manner' (Table 1). This probing is typically performed by commercial actors that see a future market potential. In the studied case, however, public actors are to an increasing extent acting on a commercial basis. Thus, many activities performed by public actors can be referred to *Entrepreneurial Experimentation*, and accordingly some public actors can be called entrepreneurs.

The indicators used for assessing *Entrepreneurial Experimentation* are the number of new entrants and diversifying firms, and the number of experiments/projects, as well as the degree of variety regarding such actors and activities (Table 5). Due to the used methodology, we delimit ourselves to the visible parts of biofuels and vehicle development, and do not consider company internal R&D projects that were not communicated in public. Such visible experimentation was often related to some kind of governance arrangement, with smaller or greater participation of commercial entrepreneurs.

Assessment of the process

There were a number of public transport companies that experimented – more or less – by introducing ethanol and biogas buses in the 1990's. Also, Scania and Volvo, who developed and supplied the vehicles in most of the projects, were active entrepreneurs. In the case of ethanol, SSEU was central in some projects and Sekab was supplying the fuel. SSEU was also the main entrepreneur in the introduction of flexifuel cars, which engaged Ford, who supplied the cars, and OK for distribution of E85. In the case of biogas, distribution was first provided by municipal companies, and later an increasing number of private (energy and fuel) companies entered.

Table 5: Indicators for assessing the key process Entrepreneurial Experimentation (Hillman *et al.*, 2011)

- Number of new entrants and diversifying established firms, degree of variety
- Number and degree of variety (technologies, applications) of experiments/projects

There was development of clean cars within Volvo (Cars) and Saab Automobile throughout the epoch, which resulted in the market introduction of Volvo bi-fuel cars in the end of the 1990's, and of flexifuel cars from both manufacturers in 2005. Since then, most multinational car manufacturers placed flexifuel models on the Swedish market, while the number of bi-fuel models remained fairly limited (see Figure 4).

Another side of *Entrepreneurial Experimentation* was represented by the actors that leased and purchased vehicles that were fuelled with ethanol and biogas. These were for example taxi companies and municipal companies in energy and public transport, and other professional vehicle users.[24]

There was some *Entrepreneurial Experimentation* in relation to second generation biofuels, as well. Chemrec developed black liquor gasification and Volvo engaged in development of heavy vehicles that could run on DME. Later, Volvo also invested in the fuel development. A range of companies were involved in various R&D programmes, such as BLG and ChrisGas, and the energy companies E.ON and municipal Göteborg Energy were projecting the synthetic biogas plant in Göteborg. There were also some smaller projects, such as VärmlandsMetanol (gasification and methanol), an ethanol pilot plant in Sveg, and a plant for hydrogenation of crude tall oil (Sunpine).

Influence of governance

For several reasons, the contribution of governance arrangements to this key process is somewhat difficult to quantify. Strictly following the theoretical framework, *Entrepreneurial Experimentation* was seldom one of the primary processes addressed by a certain arrangement, and the involvement in governance arrangements only made up a certain share of the *Entrepreneurial Experimentation* performed by the actors. Instead, as argued by a state representative, all the policies for biofuels and clean cars resulted in an environment where new alternatives were introduced, and yet more were discussed (Nilsson 2009b). However, it can be discussed whether governance should be more directly involved in supporting *Entrepreneurial Experimentation*.

Still, a few major governance arrangements may be mentioned, that addressed *Entrepreneurial Experimentation*. First, the demonstration of, and

24 When markets become more established, the kind of activities mentioned here should rather be referred to *Market Formation* (next sub-section).

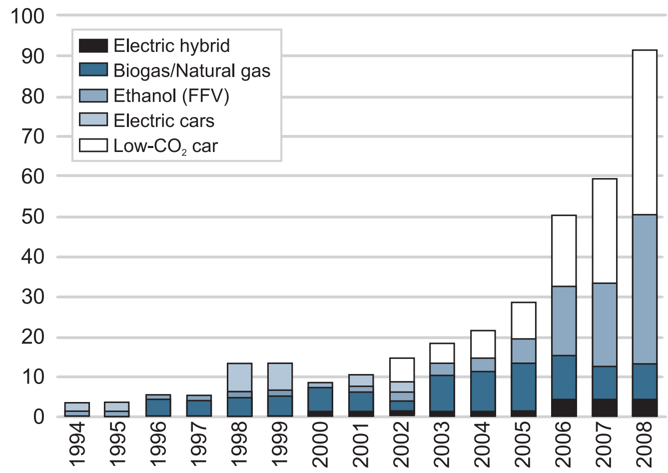

Figure 4: Number of clean car models on the Swedish market (copied, BEST 2009)

investments in vehicles and biogas production and distribution by municipal companies made a significant contribution to the process. Second, the public-private SSEU/BAFF was involved in the Stockholm Ethanol Bus Project, the flexifuel car demonstration, and various other pioneering projects that affected the further development of the TIS. Finally, several R&D projects – particularly on synthetic fuels – engaged a range of private companies that contributed human and financial capital.

3.4 MARKET FORMATION

Indicators of the key process

The process of *Market Formation* is described as 'the articulation of demand, the existence of standards, and the timing, size and type of markets actually formed' (Table 1). There are many factors influencing this process, such as market supporting schemes and established purchasing processes, of which some can be related to governance arrangements (Table 6). However, market size, the diversity and competitiveness of products, and the infrastructure, i.e. the availability of fuels and vehicles, can be considered the most aggregated indicators for this key process, that are also easily quantifiable. Here, these are used for the assessment of the process (sub-section 'Assessment of the process', below), while the specific 'influence of governance' is left for the following sub-section.

Table 6: Indicators for assessing the key process Market Formation (Hillman *et al.*, 2011)

• Market size (different measures), infrastructure
• Number and degree of variety of niche markets and customer groups
• Number and size (money) of market supporting schemes
• Purchasing processes (e.g. stated shares)

Assessment of the process

Market Formation for biofuels only included ethanol, biogas and RME. Until year 2000, the volumes were small, i.e. below 0.2 TWh. Then the volume of ethanol blended into petrol first increased for a few years until most of the petrol was in fact E5, and then it decreased due to reduced sales of petrol (Swedish Energy Agency 2010a). Since 2005, also the volumes of ethanol in E85 and bus ethanol fuel, and the amount of biodiesel blended into conventional diesel increased sharply. In contrast, the use of biogas increased more slowly and continuously during the whole epoch (Figure 5).

The cost of using E85 in a flexifuel car was lower or equal to using petrol since 2004, except for two episodes, in 2006-2007 and in 2008-2009 (BEST 2009). This resulted in reduced sales of E85 in 2009 (Swedish Energy Agency 2010a). Calculated as petrol equivalents, the price of biogas was lower than both the petrol and the diesel price since the end of 2004 (Svensk Biogas AB 2009).[25]

Not only the price, but also the availability of biofuels played a role for *Market Formation* (Figure 6). In Sweden, the number of filling stations that supplied

25 For a discussion of the biogas price in Sweden, see Ahlbäck (2003: 21-22).

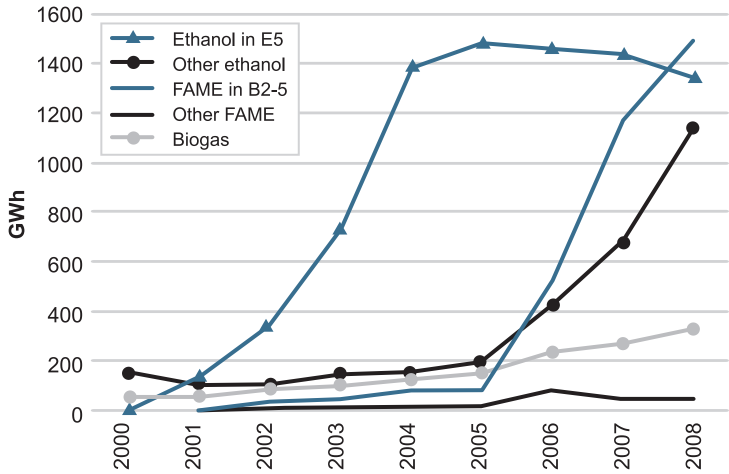

Figure 5: The use of biofuels for transport in Sweden 2000-2008 (Swedish Energy Agency 2009)

Other ethanol includes ethanol in E85 and in bus fuel, and other FAME includes various diesel fuels with RME contents higher than 5 per cent.

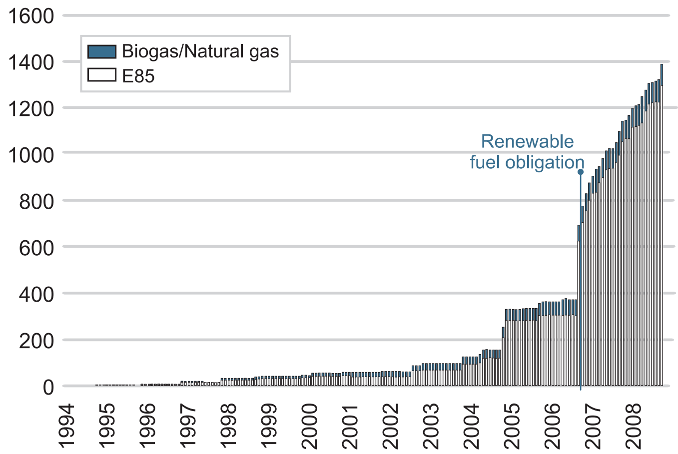

Figure 6: The number of filling stations supplying alternative fuels (copied, BEST 2009)

Here, biogas and natural gas pumps are not differentiated.

E85 increased slowly until 2005, when it doubled. In 2006, more rapid development took off, partly due to the renewable fuel obligation. Despite ear-marked additional grants from the Klimp programme, the obligation had limited effect on the number of filling stations for methane (biogas/natural gas). Similar to biogas sales, they increased only moderately through the years.

The number of ethanol buses in 1995 was estimated 280, the number of flexifuel cars was then 50-100, and there were only four trucks (SIKA *et al.,* 1996). The number of ethanol buses later reached 500, then it decreased to 400 in 2003 due to technical problems (Table 7, Rydén 2005). There is little statistics on the number of vehicles primarily fuelled by biogas, but in 1995 there were 46 of them, and in 1997, 65 biogas buses and 27 biogas trucks were ordered in Sweden (Ekelund 1997). Later numbers seldom differentiate between biogas and methane fuelled vehicles.

The differentiate trends regarding bi-fuel and flexifuel cars can partly be explained by their additional purchase price, as compared to petrol and diesel cars. This changed over time, but in general it was about one order of magnitude larger for bi-fuel than for flexifuel cars (BEST 2009). Another explanation may be that the selection of flexifuel cars increased radically in the third period (2004-2010), while the number of bi-fuel models remained low.

Summing up, markets were expanding for all the first generation biofuels. Biogas increased only slowly, while ethanol and RME started to take off around

2000 and 2005, respectively. The number of flexi-fuel (ethanol) cars increased to a relatively high level at the end of the epoch. For biogas and RME, a larger expansion of vehicles – in turn allowing for larger sales of these fuels – was yet to be seen.

Influence of governance

Market Formation is the key process that was addressed by the most arrangements in the studied case (Figure 7). It is expected that all those arrangements made some contribution to the process, but only the most influential ones are brought up here. Already in the first period, tax exemptions were introduced to make biofuels competitive to petrol and diesel; this arrangement was kept throughout the studied epoch, though it was not enough to keep up the sales of E85 at times of relatively low oil price. In the second period, a multitude of influential arrangements were implemented. On the national level, the fringe benefit tax for company cars was reduced and investment grants were given to local biogas projects. On the local and regional levels then, there were primarily biogas investments, vehicle procurements and subsidies, and parking fee subsidies. In the third period, state actors became obliged to purchase clean cars, the renewable fuel obligation for filling stations went into effect, and clean cars were exempted from congestion tax in Stockholm for some time. The clean car premium was introduced, and was later replaced by a vehicle tax exemption. The adjustment of the diesel standard resulted in a dramatic market increase for RME. With a few exceptions, once introduced, most arrangements remained in effect for the rest of the epoch. Out of the flora of arrangements, the tax exemptions, the fringe benefit tax reduction, and the parking fee subsidies are often mentioned by key actors as crucial for *Market Formation*.

A wide range of arrangements addressed *Market Formation*, and typically these did not formally exclude any alternative; nonetheless, they were inadequate for second generation biofuels, as these technologies were not ready for commercial use. Concerning first generation biofuels, governance implicitly favoured ethanol, as compared to biogas and RME. According to the representative from the farmers' organisation, there were two major obstacles for RME: quality problems pointed to the need for a clear quality declaration, and the lack of a distribution network for pure FAME. For biogas, any problems with *Market Formation* were mainly related to the higher cost. Following the TIS approach, system development would have benefited from governance correcting for the imbalance between alternatives, which in turn could have stimulated variety.

3.5 LEGITIMATION

Indicators of the key process

The process of *Legitimation* is described as 'a matter of social acceptance and compliance with relevant institutions' (Table 1). This is affected by a range of factors primarily related to the expression of opinion by various actors and their weight in terms of, e.g., size, trust and power. Indicators used are the public opinion concerning the TIS, assessments, articles/features in media, lobby activities, and the number and weight of TIS actors (Table 8).[26] Volume and variety are here described in text, but in principle a more strict quantification can be made.

Assessment of the process

In Sweden, the public opinion towards sustainable technology was generally positive, though various actors demonstrated slightly different views in the studied epoch. Already early, politicians were positive to ethanol, as were also lobbyists from the farmers' organisation and SSEU/BAFF. Other organisations, such as the clean car organisations and the Green Motorists, were instead positive to all kinds of alternatives to conventional petrol and diesel vehicles, while the Swedish Society for Nature Conservation added a more critical view of road transport in general. Assessments and statements by researchers and consultants – but also by the Swedish Energy Agency and the Swedish Road Administration – were often negative to biofuels for transport. When selecting between biofuel alternatives, though, they were typically positive to synthetic fuels from wood, such as methanol and DME, and sometimes also biofuels produced in tropical regions. Vehicle manufacturers and importers – that partly worked through their Swedish association (BIL Sweden) – were primarily advocates of low-level biofuel blends, which required no adjustments of vehicles. A similar standpoint was communicated by the fuel industry association (SPI); their interest in pure biofuels grew, however, in accordance with increasing market opportunities. Among many of the actors, first generation biogas from various types of organic waste was considered good for the environment. It was unclear, though, how large the potential was. In addition, most actors could agree that second generation biofuels were necessary to meet the soon-coming needs for biofuels worldwide in a sustainable way.

The public awareness of the need for sustainable transport and the merits of biofuels increased radically

26 See also *Enrepreneurial Experimentation* on the assessment of number and weight of actors.

Table 7: The number of ethanol and methane vehicles in Sweden (MILJÖfordon.se 2009)

Before 2003, the number of ethanol buses reached 500, then it decreased due to technical problems (Rydén 2005)

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Bi-fuel cars	1 500	1 640	2 500	3 440	4 500	6 600	10 500	12 900	15 000
Flexifuel cars	250	890	3 500	7 980	13 300	21 400	46 700	81 300	138 000
Ethanol buses	-	-	-	400	380	370	490	490	510
Methane buses and trucks	-	-	-	680	780	900	1 120	1 160	1 300

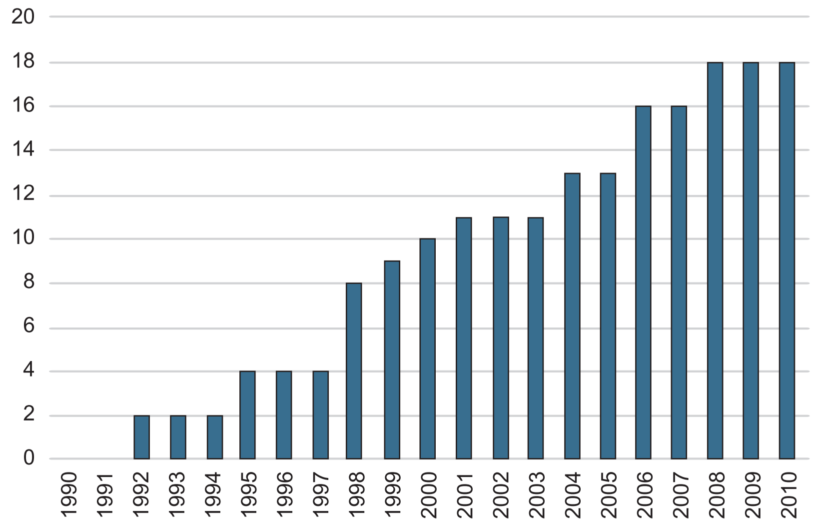

Figure 7: Number of governance arrangements in effect over the years, which addressed Market Formation as primary or secondary process

Table 8: Indicators for assessing the key process Legitimation (Hillman *et al.*, 2011)

- Public opinion towards various alternatives
  Number of (positive/negative) articles/features
- Number and degree of variety of lobby groups active in the system
- Number and degree of variety of lobby actions
- Number and 'weight' of actors
- Number of (positive/negative) assessments

since around 2005, when the number of biofuelled cars increased, as well. One lobby action that attracted much attention was the introduction of Saab BioPower – organised in cooperation with BAFF – which entailed heavy advertising and an information campaign that addressed Saab retailers around Sweden. It also influenced the public opinion in that it showed that clean cars could in principle offer better performance than conventional cars.

Notwithstanding the general awareness, there was limited attention to the differences between alternatives, e.g. with respect to environmental and social performance. Such issues were raised in a larger public debate in 2007-2008 that resulted in a less positive view of biofuels, and to some extent a differentiation between better and worse alternatives was gaining ground. As the implementation of sustainability criteria at the EU level was lagging behind, both Sekab and the Nordic Ecolabel introduced their own certification schemes for ethanol and alternative fuels, respectively. Another effect of the sustainability debate was that biofuels, to some extent, were replaced by electric vehicles as the major promise for more sustainable road transport. The sobering-up in the field of biofuels was welcomed by the environmental NGO (Nilsson 2009c). There were also signals from politicians in that some arrangements were questioned or cancelled, primarily for economic reasons.

Influence of governance

As with *Entrepreneurial Experimentation*, the contribution of governance to this process is difficult to quantify. In the studied case, arrangements only occasionally directly supported lobby actions and the like. Instead, governance arrangements influenced the number and "weight of actors" by supporting organisations to work with biofuels. Over time, organisations that worked with biofuels typically also came to function as advocates of 'their alternative(s)' contributing to the *Legitimation* process. Furthermore, the number of articles/features and the public opinion were influenced by all kinds of activities and events in society, of which governance was one; in fact, not only governance arrangements, but all statements communicated by governing actors – that had bearing on biofuels – possibly influenced *Legitimation*. For example, smaller assessments performed by governmental agencies and researchers made small contributions to the overall picture that determined the public opinion towards various alternatives.

To some extent, *Legitimation* followed the state of knowledge regarding the technical and environmental performance of biofuels. However, it might have been a problem that most messages were put forward by stakeholders that supposedly looked after their own interests. Also, this potentially contributed to the exaggerated and simplistic media reporting and debate. For instance, the public opinion seemed too optimistic about ethanol around 2005, and maybe too negative in 2007-2008. Though there were researchers that provided more neutral and nuanced information, particularly in the third period, governance could have played a role in stabilising the debate through official assessments. Finally, a problem specific for biogas was the lack of heavy and organised advocates comparable to those active in the ethanol field (Lagerkrantz 2009).

3.6 RESOURCE MOBILISATION

Indicators of the key process

The process of *Resource Mobilisation* is described as 'the extent to which the TIS is able to mobilise competence/human capital and financial capital' (Table 1). The indicators for this process are quite straightforward: volume of money available and number of people working in different parts of the TIS (Table 9). Similar to the previous processes, the results are here described in text rather than included in a formal quantification. The reason for this methodological choice is the time needed to acquire a fully complete data set, and this was not feasible in relation to the present report.

Assessment of the process

The most important contribution of financial resources in the field of biofuels was allocated through the exemptions from energy and CO_2 taxes that were introduced in Sweden in the 1990s and that were in effect since then. Another important arrangement was the reduction of the fringe benefit tax for company cars used off duty. The volume of money allocated certainly increased with rising sales of biofuels and cars, respectively. There were also some other market incentives that contributed resources, such as the clean car premium and vehicle tax exemption on the national level, and parking fee subsidies and congestion tax exemption on the local/regional level.

Procurements of biofuelled vehicles and investments in biogas production and distribution were mostly funded by municipalities and municipal companies, with significant contributions from the two large investment programmes LIP and Klimp.[27] The investments also

27 The funding here refers to administration and additional vehicle costs (as compared to conventional vehicles).

Table 9: Indicators for assessing the key process Resource Mobilisation

(Hillman *et al.*, 2011)

- Volume of money available in different parts of the system
- Number of people working (engineers, managers, etc.) with various alternatives

implied that people at the municipal companies set out to work with, e.g., biogas, in various ways.

Much financial resources were channelled through R&D programmes funded by the state, and typically co-funded by private companies and municipal actors. Some activities were also co-funded by EU programmes. In addition to the larger *programmes*, there was a multitude of separate *projects and studies* funded by various funding organisations. All these R&D activities of course involved a range of people at governmental ministries and agencies, universities, institutes, and NGOs. To these can be added the public and private financiers of various organisations, such as companies, industry associations, and NGOs, that contributed both money and people.[28]

Before the first bi-fuel and flexifuel cars were released on the market, there were often problems to find resources internally for Volvo Cars and Saab Automobile. For many years, the Volvo bi-fuel was said to give very small profits, and it was internally questioned and even stopped for some years. Similarly, in 2004, Scania decided to cancel the development of its ethanol engine, a decision that later was changed (Rydén 2009). Despite those problems, there were actually people who worked with engine and vehicle development, which resulted in concept vehicles for most kinds of biofuels and a number of market releases.

Influence of governance

As they contributed economic resources, many arrangements primarily addressing *Market Formation largely* influenced also this process, such as tax exemptions, subsidies, and investments of various kinds. In comparison with R&D investments, the volume of money allocated to market-directed arrangements was large (Hillman and Sandén 2008). Here we focus on the influence of governance arrangements not captured by the *Market Formation* process (section 3.4*)*.

One type of arrangement present during the whole epoch was the support for R&D and demonstration programmes, funded by governmental agencies and EU programmes, and typically co-funded by municipal, regional and private actors, either through money and/or people. In the third period, also larger pilot and demonstration plants were supported, which implied the use of larger resources. The two large investment programmes (LIP and Klimp) present in the second and third periods contributed a considerable volume of money that were crucial for municipal investments in biogas and clean cars. Also this money was to be matched by municipalities and companies. Finally, a particular form of governance occurred in the north-east, when a regional consortium – involving a number of municipal energy companies – bought Sekab.

If new technology is to be developed, several interviewees see the lack of funding as a problem, (Herland 2009; Kärrberg 2009; Lagerkrantz 2009). According to the farmers' representative, the industry had limited possibilities to invest in new technology, which indicated a need for more cooperation between the state and the industry (Herland 2005). Also, the Volvo Cars representative considered investments in second generation biofuels too small (Kärrberg 2009). To some extent, there is always need for more resources to develop and test new technology, and it can be discussed how the state could make more resources available for biofuels, without sacrificing too much in other fields.

The interviews with representatives from both Volvo Car Corporation and Chemrec confirmed that there were enough competence in Sweden (Kärrberg 2009; Landälv 2009). However, Chemrec could not find any owner with the requested technological competence within the country (Landälv 2009). Also Sekab had problems with ownership. In the third period, it was partly owned by municipal companies in its own region, but they were supposed to sell the business when considered suitable (Rydén 2009).

3.7 DEVELOPMENT OF POSITIVE EXTERNALITIES

The process of *Development of Positive Externalities* is described as 'the generation of positive external economies, such as pooled labour, knowledge spillovers, specialised intermediate goods, and complementary

28 See further the subsection on Knowledge Development and Diffusion (section 3.1).

products, services and infrastructure' (Table 1). However, as discussed by Bergek *et al.* (2008b), there are also other possible definitions related to, e.g., the interconnectedness between various alternative technologies within the TIS, and between the TIS and the external environment. The process is typically dependent on feedback loops from other processes. In the studied case, a number of such overlaps can be identified: *Market Formation* to some extent already involves infrastructure, intermediate goods, and services; knowledge spillovers may be captured by external influence on *Knowledge Development and Diffusion*, and pooled labour could be part of *Resource Mobilisation*. However, there are no indicators for *Development of Positive Externalities* developed for the framework, so at this stage we choose not to include this process in our analysis.[29]

3.8 OVERALL FUNCTIONALITY

In this sub-section the aggregation of the key processes analysed above (3.1-3.6) is used to evaluate the overall functionality of the TIS, and how this was influenced by governance. Potential functionality gaps regarding processes and technologies are discussed, as well as the role of governance in relation to such gaps. Also, the influence of external factors on TIS functionality is summarised and their potential moderating effect on the influence of governance on functionality is examined.

On an aggregated level, the Swedish biofuels TIS was functioning increasingly well, with all the key processes present and developing mostly in a positive direction with respect to the scope and scale of activities. However, taking a closer look, there were indications of problems in relation to specific processes and technologies. Our analysis shows that there were little *Entrepreneurial Experimentation* and *Resource Mobilisation* from private actors alone, which may indicate that the market was upheld by governance and is not expected to stand on its own, but also that public investments were possibly outcompeting potential private initiatives.

Another result of the analysis is that there was too much focus on *Legitimation* of the use of (imported) ethanol in relation to other parts of the TIS. Brazilian sugar cane ethanol represented the largest share of the biofuels used in Sweden in the studied epoch. Particularly, it was crucial at the time of the radical market increase and improved public awareness of biofuels around 2005. Though not always made explicit, it thus became the symbol of all kinds of biofuels in the public debate. When sustainability concerns around Brazilian ethanol were brought up, this affected the reputation of biofuels in general. On top of this, fuels from biomass were generally questioned due to the need for large land areas and the potential impact on food prices.

In this context, promising results for second generation biofuels would have been welcome to strengthen TIS functionality, but still no significant volumes were produced. More support to strengthen *Knowledge Development and Diffusion* and *Resource Mobilisation* could potentially have changed this picture. Furthermore, sustainability criteria that could have an *Influence on the Direction of Search* towards more sustainable biofuels were not in place at the EU level until the end of the studied epoch, which probably slowed down TIS development.

In general, governance addressed processes that needed support, but with limited resources the priorities between processes and technologies can be questioned. The previous sub-section also points to some problems with TIS functionality. First, the *Market Formation* process, which was heavily supported by governance, only concerned first generation biofuels: In terms of energy, ethanol and RME were dominating. Referring to uncertainties regarding sustainability and large scale potential of present supply chains for those fuels, the market focus was too strong in relation to the development of new technologies. Most actors could agree that second generation biofuels were needed soon, but still *Knowledge Development and Diffusion, Entrepreneurial Experimentation* and *Resource Mobilisation* were attracting too little support. This could have been facilitated through governance, to begin with by addressing *Influence on the Direction of Search*.

Landscape and regime factors and other TISs had both a direct impact on the key processes, as well as indirect impact through actions related to the biofuels TIS. Landscape factors related to environmental issues, oil supply, and sustainability were the main driving forces that affected the development of the TIS for biofuels in Sweden. Though less pronounced, also energy security and agricultural development were influential throughout the studied epoch.

In the first period, local emission problems were a key argument for the work with biofuels. In the second period, the oil price started increasing, and in the third period, climate change and global warming became a top priority around the world. All these

29 This is in line with Hekkert *et al.* (2007).

landscape factors primarily affected *Legitimation* and *Influence on the Direction of Search* towards biofuels. Particularly, the debates in the third period probably moderated the influence of governance arrangements addressing, e.g., *Market Formation*. The widening of the debate to incorporate a range of sustainability concerns influenced also the choice between various biofuels, and between biofuels and other alternatives (described below).

The fuel and vehicle regimes were generally hesitant about biofuels; they were somehow in favour of low-level blends that entailed only minor adjustments of vehicles and distribution systems. An almost trivial result from our analysis is that the biofuels that were most aligned with the fuel and vehicle regimes were more successful in terms of *Market Formation*. This could be expected, as first generation ethanol and biodiesel were also cheaper than the alternatives. Furthermore, there were some biofuels that were equally aligned, which were later in their development, such as biodiesel from hydrogenisation, second generation ethanol, and synthetic methanol. When it comes to biogas, it was instead partly aligned with the waste and water regimes that opened for synergy effects in the treatment of waste material. Finally, the production of raw materials for biofuels was to a large extent aligned with production within the agricultural regime. The positive – even embracing – attitude of the agricultural regime towards biofuels implied both lobbying and investments in biofuels, influencing most key processes, e.g., *Legitimation, Market Formation,* and *Resource Mobilisation*.

In the third period, fuel-efficient diesel vehicles with particle filter and relatively low CO_2 emissions were put forward as a more sustainable alternative to petrol vehicles. Some of those cars were also covered by the national definition of clean cars, as were a number of small and fuel-efficient petrol cars. Though not offering lower emissions than biofuelled vehicles, their success came partly at the expense of reduced *Legitimation* for biofuels. In addition, they had *Influence on the Direction of Search* in that they offered alternatives to biofuels. Potentially even more sustainable than biofuels then were the technologies related to electrification, such as hybrid vehicles, plug-in hybrids and electric vehicles. At the end of the epoch, several vehicle manufacturers announced the introduction of such models in the coming years. These technologies benefited from good assessment results and little land use compared to biofuels, thus offering less competition between food and energy production. It is likely that the relative importance of EU biofuel policies was weakened due to promising alternative technologies.[30]

Also alternative fuel developments abroad and in Sweden – that analytically could be referred to other TISs – helped *Market Formation* in the Swedish biofuels TIS. First, natural gas vehicles and equipment marketed worldwide could equally be used for biogas. Second, flexifuel vehicles and ethanol fuels in the US and Brazil displayed what was technically possible, and, more concrete, the first (Ford Taurus) flexifuel cars and large volumes of Brazilian ethanol could be imported to Sweden. Finally, also the production and use of biodiesel was increasing worldwide, a development of which Sweden was part.

As mentioned, various landscape factors had an impact on the price relation between petrol and E85, which in turn was crucial for E85 sales. Particularly important were the oil price, the import tax and currency relations. Consequently, at the time of the economic recession and falling oil price, there was reduced interest in alternatives, which became more expensive in relation to petrol and diesel. Furthermore, the price of the raw materials wheat, sugar cane and rapeseed oil influenced the profitability of first generation ethanol and biodiesel, and thus the growth of the TIS.

Before its implementation, the renewable fuel obligation was criticised by many actors for that it would only benefit ethanol. This was also what happened; the obligation resulted to an overwhelming degree in E85 pumps. That more biogas pumps were not installed – despite specified grants – can be explained by poor alignment with the fuel regime and the less advanced status of the TIS.[31]

Finally, there were indications that the changing ownership of the Swedish car manufacturers affected their involvement in various clean car technologies, influencing *Knowledge Development and Diffusion* and *Resource Mobilisation.* One example concerns the flexifuel car procurement that resulted in the introduction of Ford Focus flexifuel on the Swedish market shortly after Volvo was acquired by Ford. Another example points to the role of various brands owned by GM, where Saab produced ethanol cars and Opel was an important methane vehicle producer,

30 To be correct, both hybrid and plug-in hybrid vehicles can in principle be constructed to run on biofuels. In the studied epoch, though, they were mainly seen as competitors to biofuels.

31 For the most part the methane pumps in Sweden were not hosted by established filling stations.

while hybrid and fuel cell technology was developed at group level (Bergström 2005). However, to allow for more certain results, these kinds of internal affairs need to be traced on a more detailed level than done for this report.

4 CONCLUSIONS

The focus of this report is the connection between governance arrangements and a number of key processes in the development of the innovation system for biofuels in Sweden between 1990 and 2010. The status of key processes adds up to the overall functionality of the technological innovation system (TIS), indicating the potential for development, diffusion and use of a particular technology or knowledge area. In general, TIS functionality is determined by activities emerging from its constituting elements, and from external factors on different socio-technical levels (landscape, regime, and other TISs). With help from five sub-questions (SQ1-5, see section 1), this report primarily addresses one main research question (MQ):

> *MQ In what way did various governance arrangements influence the functionality of the innovation system for biofuels in Sweden between 1990 and 2010?*

Key findings related to the sub- questions (marked by parentheses) are summarised in section 4.1. Furthermore, the work with the report was largely guided by the theoretical framework and analytical procedure proposed by Hillman *et al.* (2011), and experiences from the implementation are discussed in section 4.2. That section also contains some notes for future studies.

4.1 KEY FINDINGS

The TIS for biofuels was mainly well functioning in that all key processes were present and developed in a positive direction (SQ1). The market share for first generation biofuels increased, and selected R&D of second generation biofuels advanced towards demonstration plants. Through the years a number of landscape factors were driving the development of biofuels in Sweden, primarily affecting *Legitimation* (SQ2): Local emission problems were of primary concern in the 1990s, the oil price started to increase around year 2000, and the debate on climate change soared since 2005, followed by a wider sustainability debate. Largely influenced by such landscape factors, governance arrangements played a decisive role for the functionality of the TIS throughout the studied epoch. Also industry activities were affected, and increased in intensity particularly in relation to the market expansion for first generation biofuels since 2005. As suggested by the framework used, the influence of governance arrangements on key processes was also moderated by external factors. On a general level, at times of intense public debate on climate and sustainability, biofuel governance gained additional attention and arrangements were probably more effective in stimulating the development.

From a historical account, we see that a large range of governance arrangements were present in the studied TIS (SQ3); a categorisation with various dimensions of governance allowed for the identification of multiple arrangement types (see Appendix). The influence of governance (SQ4) and external factors (SQ5) on key processes and technologies is summarised in the following, and some functionality deficits and recommendations for policy are elaborated.

First, considering *Knowledge Development and Diffusion* and related *Resource Mobilisation,* a large share of these processes was the result of R&D and demonstration programmes with a certain degree of public involvement from various levels. Normally, such programmes also entailed private participation and co-funding.

Second, throughout the studied epoch, a range of governance arrangements had an *Influence on the Direction of Search*. The most influential ones were an agreement on the national energy policy in 1991, a national introduction strategy of 2001-2002 by four governmental agencies', and last but not least a number of EU documents released since 2001. The agreement and the strategy favoured ethanol and synthetic fuels, respectively, while EU directives set targets for the market introduction of biofuels. Later, also sustainability issues were incorporated in the EU policies.

Third, *Market Formation* for first generation biofuels benefited from an increasing number of arrangements since around year 2000, which entailed public procurements of vehicles, and various economic incentives and obligations related to biofuels and clean cars. Until then, the fuel and vehicle regimes were largely hesitant, as they preferred low-level blending of biofuels in petrol and diesel. At the same time, the influence of governance on the Swedish biofuels TIS was helped by the development of alternative fuel technology abroad and in Sweden, such as natural gas vehicles and equipment worldwide, and ethanol fuels and flexifuel vehicles in Brazil and the US.

Fourth, a number of other alternative technologies that could reduce the environmental impact of road transport emerged in the studied epoch, such as cleaner fossil fuels, exhaust treatment, and more fuel-efficient vehicles. Particularly, vehicle electrification competed for interest and money at the end of the studied epoch, possibly affecting *Market Formation* and *Resource Mobilisation f*or biofuels negatively.

The analysis of key processes also points to some deficits in functionality and how governance (could have) played a role. Concerning price relations, despite various economic incentives the profitability of ethanol and RME was poor from time to time, due to the fluctuations in prices for raw materials and the competing petrol and diesel. These affected investments, and more visible the sales of E85. However, most actors expected that the oil price would increase in the long term. Biogas suffered from being more expensive than ethanol and RME and not being aligned with the fuel and vehicle regimes; this was only partly compensated by large national investment programmes and local public investments etc. In addition, *Market Formation* for biogas was hampered by the lack of strong organisations in the field that could have addressed *Legitimation* and *Knowledge Development and Diffusion* through lobbying and information, similar to what SSEU/BAFF and the farmers' organisations did for ethanol and RME.

Another result of the analysis is that there was too much focus on *Legitimation* of the use of ethanol in relation to other parts of the TIS. This was indirectly caused by governance that addressed the other key processes, particularly *Market Formation* for first generation biofuels, which brought in actors that functioned as advocates of certain alternatives. The high degree of alignment with the vehicle and fuel regimes, and the narrow landscape focus on climate change since 2005 further added to this development. Later, when wider sustainability concerns entered the debate, biofuels were generally disfavoured, while other alternatives gained ground, such as vehicle electrification and so-called clean diesel technology. More focus on other alternatives – by strengthened *Influence on the Direction of Search* and *Knowledge Development and Diffusion* – could have avoided the general backlash in the *Legitimation* of biofuels. Also, the actual stage of development for the second generation would potentially then have been more in line with the high ambitions expressed in policy documents.

Providing recommendations for policy, it seems that there is a problem when different processes come 'out of phase'. In the present case, the ambitions regarding new technologies expressed in policy documents was not reflected by actual market developments and research results. This can be explained by that *Legitimation* was heavily affected by *Market Formation* and not only by governance that addressed *Influence of the Direction of Search.* In addition, the limited success regarding *Knowledge Development and Diffusion* for second generation biofuels amplified this imbalance, while it was somewhat reduced by the sustainability debate at the end of the epoch.

The decisive role of governance arrangements may have created a TIS that were more or less dependent on governance support; there were little *Entrepreneurial Experimentation* and *Resource Mobilisation* from private actors alone. Also, the effect of governance on various alternatives was to a high degree determined by technology status, which meant that seemingly neutral policies favoured first generation biofuels, particularly ethanol and RME. In the light of the recent sustainability debate and limited prospects for future mass markets, the heavy support for first generation biofuels – as compared to the second generation – can be questioned. It seems plausible that this profile of governance support discouraged from private initiatives with another focus.

The problems with functionality of the studied TIS point to the need for scrutiny of price instruments and priorities of expenditure in the Swedish (and the EU) context. Market introduction of first generation biofuels may require stimulation, but commitment and costs should be put in relation to other activities in the field of biofuels, and potential larger needs in other parts of the TIS. Also, the secondary effect of entering actors acting as advocates – that increase *Legitimation* – should be taken into consideration.

4.2 DISCUSSION

The main topic for discussion is related to the usefulness and value of the kind of extensive analysis pursued for this report. The merits of each element of the framework are discussed, and some notes for future studies are offered. First, the theoretical framework adds an explicit governance perspective to the TIS approach, in that it enables a separation of governance and functions. Our focus on the influence of governance on functionality originates in the assumption that this is what can be manipulated by various actors in order to strengthen the TIS.[32]

Second, the key processes draw attention to the relevant activities of the TIS, and equally important, they help identify what is weak or missing. In this context, technology specificity seems to be a less pronounced aspect of the TIS approach, though it may be crucial for functionality which specific technologies of the TIS that are supported from time to time. The issue is closely related to the choice of system boundaries, which could be more or less narrow with respect to the technologies included.[33] The opening for a discussion of alignment and interaction between technologies inside and outside a studied TIS is something that could be added to a future version of the GIST framework. Another help in this respect would be the explicit inclusion of how governance was developed, and not only its implementation.

Third, external factors are useful to help differentiate what is driving the development of the TIS from outside, and what is accomplished within the TIS. This is needed in order to draw conclusions on what could have been done differently and give recommendations for the future.

Finally, the relatively time consuming TIS analysis necessitates a discussion on the potential for less detailed studies. For example, adjusted delimitations regarding temporal or technological scope and level of aggregation may reduce the volume of work, without sacrificing too much understanding of the case. However, the selection of activities and arrangements to include need to be made with care, as it is difficult to judge in advance what were influential contributions to the overall functionality. Furthermore, the data set may possibly be reduced, though the different – and shifting – stakes and goals of different actors indicate that a certain amount of interviewees complemented by published documents are necessary to avoid bias. A possible help in this respect could be the use of a questionnaire sent out to a larger number of actors than those interviewed.

32 In this study, we only include governance with public involvement, but in principle public actors need not be involved in all governance

33 See also Hillman and Rickne (forthcoming) and Sandén and Hillman (2011).

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APPENDIX

CATEGORISATION OF GOVERNANCE ARRANGEMENTS

The categorisation of governance arrangements proposed by the theoretical framework suggests further analysis of the studied material; instead of discussing how specific arrangements influenced key processes, different types of arrangements can be identified and used in the analysis. Possible questions concern, e.g., what arrangement types that can be identified, how arrangement types varied over time, and how different arrangement types influenced functionality. This report is not taking the analysis of arrangement types any further, but the arrangements identified in the studied case were categorised in line with the dimensions of the categorisation.[34]

We characterise three dimensions of governance (Table 10). On 'Who governs?', we are interested in, first, whether the state alone or in collaboration with private actors orchestrate the governance arrangement, and, second, at what level of governance the arrangements are orchestrated, from the local to the global. For the 'How?' question, we are interested in, first, the mechanism of governance, whether regulative, market-based, normative or cognitive; and, second, whether the target of governance is on the supply (push) or on the demand (pull) side, or both. The 'What?' dimension concerns, first, the target of the governance arrangement in terms of the seven key processes, and, second, whether it covers the whole sector (e.g., transport), the TIS as a whole (e.g., hybrid vehicle technologies), or a subsystem within the TIS (such as parallel hybrid technology).

Using the example of fuel tax exemptions for biofuels, it can be characterised in the three dimensions as follows. The tax exemption is orchestrated by the state (no/little private involvement), at the national level. It works through a market-based mechanism, and operates on the demand side (technology pull). It aims to influence *Market Formation* for all kinds of fuels produced from biomass (whole system). Another example is R&D programmes for second generation biofuels. Such programmes are orchestrated by the state but often strongly influenced by industry (no/little or moderate involvement), and they work at either EU or national level. They have an effect primarily through a cognitive mechanism and are directed at technology push actors, including researchers, manufacturers, and suppliers. The programmes mainly aim at *Resource Mobilization* and *Knowledge Development and Diffusion,* and they typically operate on sub-system level.

34 The categorisation and selected dimension are used as a base for other publications related to the GIST project.

Table 10: Three dimensions of governance arrangements (Hillman et al., 2011)

Who governs?
- Governance level: 1. local/regional , 2. national, 3. EU, 4. global
- Private involvement: 1. no/little, 2. moderate, high

How to govern?
- Mechanism: regulative, market-based, normative, cognitive
- Push/pull: push, pull, both

What to govern?
- Key process(es):
  - KDD: Knowledge Development and Diffusion
  - IDS: Influence on the Direction of Search
  - EE: Entrepreneurial Experimentation
  - MF: Market Formation
  - Leg: Legitimation
  - RM: Resource Mobilisation
- Technology specificity: 1. sector, 2. system, 3. subsystem

All governance arrangements included in the present case study were categorised in the dimensions mentioned, and are listed in Table 11. As a first illustration, the share of governance arrangements that were allocated to each alternative for each dimension is shown in Figure 8. On 'Who governs?', this shows that most arrangements were implemented on a national level with no or little involvement of private actors. The picture is more fragmented when it comes to 'How to govern?', with both push and pull arrangements working through cognitive, market and regulative mechanisms. On 'What to govern?' both system and sub-system levels were common, while *Market Formation, Knowledge Development and Diffusion* and *Influence on the Direction of Search* were the mostly addressed key processes.

The number of arrangements is a somewhat rough indicator that has some primary disadvantages. First, it does not differ between large and small R&D programmes or economic incentives. On the other hand, economic cost – another possible indicator – would not be meaningful for a comparison between,

Table 11: List of governance arrangements with start/end year and categorisation in the six dimensions (two columns for key processes), as introduced in Table 10

Arrangement	Start year	End year	Govern-ance level	Private involve-ment	Mecha-nism	Push/ pull	Tech-nology specifi-city	Primary process	Sec-ondary process
Stockholm ethanol bus project	1990	1993	1	2	Cognitive	Push	3	KDD	EE
Foundation for Swedish Ethanol Development (SSEU)	1990	1999	2	2	Normative	Both	3	Leg	KDD
Biogas in Linköping	1990	2010	1	1	Cognitive	Push	3	KDD	EE
Three party agreement	1991	1991	2	1	Regulative	Push	2	IDS	-
Biofuels Programme	1991	1997	2	2	Cognitive	Both	2	KDD	RM
Biogas and ethanol facilities	1992	2010	1	1	Market	Push	3	EE	MF
Ethanol and biogas bus purchase	1992	2010	1	1	Market	Push	3	EE	MF
Ethanol Development Programme	1993	1997	2	1	Cognitive	Push	3	KDD	RM
Flexifuel car demonstration	1994	1996	1	2	Normative	Push	3	EE	KDD
Commission on Alternative Transport Fuels (SOU 1996:184)	1995	1996	2	1	Cognitive	Push	2	KDD	IDS
Clean vehicle organisations	1995	2010	1	1	Normative	Pull	2	KDD	MF
Fuel tax exemptions	1995	2010	2	1	Market	Pull	2	MF	-
KomKom ethanol introduction strategy (SOU 1997:35)	1996	1996	2	1	Cognitive	Both	3	IDS	-
Various EU programmes	1996	2010	3	2	Cognitive	Both	2	KDD	RM
Biogas as a Vehicle Fuel (SOU 1998:157)	1998	1998	2	1	Cognitive	Push	3	KDD	-
Local Investment Programme (LIP)	1998	2002	2	1	Market	Pull	1	RM	-
Ethanol from Forest Raw Material	1998	2004	2	1	Cognitive	Push	3	KDD	RM
Clean car sharing	1998	2010	1	2	Market	Push	2	MF	-
Clean vehicle procurements	1998	2010	1	1	Market	Pull	2	MF	IDS
Municipal clean vehicle incentives	1998	2010	1	1	Market	Pull	2	MF	-
Parking fee subsidies	1998	2010	1	1	Market	Pull	2	MF	-
SRA travel policy	1998	2010	2	1	Market	Pull	1	IDS	-
BioAlcohol Fuel Foundation (BAFF)	1999	2010	2	2	Normative	Both	3	Leg	KDD
Fringe benefit tax reduction	1999	2010	2	1	Market	Pull	2	MF	-
Local clean car subsidies	2000	2010	1	1	Market	Pull	2	MF	-
Commission Communication on Alternative Fuels	2001	2001	3	1	Normative	Both	2	IDS	-
Introduction of Biofuelson the Market	2001	2002	2	1	Normative	Push	2	IDS	-
Biogas in Vehicles	2001	2004	2	2	Cognitive	Push	3	KDD	-
Biogas West	2001	2010	1	3	Market	Push	3	KDD	MF
Black liquor & DME	2001	2010	2	3	Cognitive	Push	3	KDD	RM
EU Biofuels Directive	2003	2003	3	1	Regulative	Both	2	IDS	-
Commission on Renewable Transport Fuels	2003	2004	2	1	Cognitive	Both	2	KDD	-
FALT (Research Programme on Alternative Transport Fuels)	2003	2006	2	2	Cognitive	Push	3	KDD	RM
Climate Investment Programme (Klimp)	2003	2008	2	1	Regulative	Pull	1	RM	-
National definition of clean cars	2004	2005	2	1	Regulative	Pull	1	IDS	-
ChrisGas pilot plant	2004	2009	3	2	Cognitive	Push	3	KDD	RM
Ethanol Bus (and Truck) Initiative	2004	2010	2	1	Market	Pull	3	MF	IDS
Ethanol pilot plant	2004	2010	2	1	Cognitive	Push	3	KDD	RM
State actors' purchase of clean cars	2004	2010	2	1	Regulative	Pull	2	MF	-
Saab BioPower release	2005	2005	2	3	Normative	Push	3	Leg	-
CO_2-based vehicle tax	2005	2010	2	1	Regulative	Pull	1	MF	-
Sekab ownership	2005	2010	1	3	Several	Push	3	RM	-
Diesel standard adjustment	2006	2006	2	1	Regulative	Push	3	MF	-
EU Strategy for Biofuels	2006	2006	3	1	Cognitive	Both	2	IDS	-
Congestion tax exemption	2006	2008	1	1	Regulative	Pull	2	MF	-
European Biofuels Technology Platform	2006	2010	3	3	Cognitive	Both	2	KDD	-
GoBiGas	2006	2010	2	3	Cognitive	Push	3	KDD	RM
Renewable fuel obligation	2006	2010	2	1	Regulative	Push	2	MF	-
Clean car premium	2007	2009	2	1	Market	Pull	2	MF	-
Ethanol energy combine	2008	2010	2	2	Cognitive	Push	3	KDD	RM
Nordic Ecolabel Certification	2008	2010	2	2	Market	Pull	1	MF	Leg
Vehicle conversion law	2008	2010	2	1	Regulative	Pull	2	MF	-
EU RES Directive	2009	2009	3	1	Regulative	Both	2	IDS	-
EU CO2 from cars	2009	2010	3	1	Regulative	Push	1	IDS	-
Vehicle tax exemption	2009	2010	2	1	Regulative	Pull	1	MF	-
EU sustainability criteria	2010	2010	3	1	Regulative	Pull	2	IDS	MF
National biogas strategy	2010	2010	2	1	Normative	Both	3	IDS	-

Note: Due to the scope of the study, arrangements starting before 1990 or ending after 2010 are nonetheless indicated to start/end these years.

e.g., regulations and R&D support. Second, the level of aggregation is more or less subjective and the present list of governance arrangements reveals several overlaps. For instance, SSEU/BAFF was involved in the flexifuel car demonstration that was funded by the Biofuels programme, and the Local Investment Programme (LIP) funded clean car subsidies. These points show that there is need for the use of several indicators concurrently in order to be able to draw any conclusions from the material.

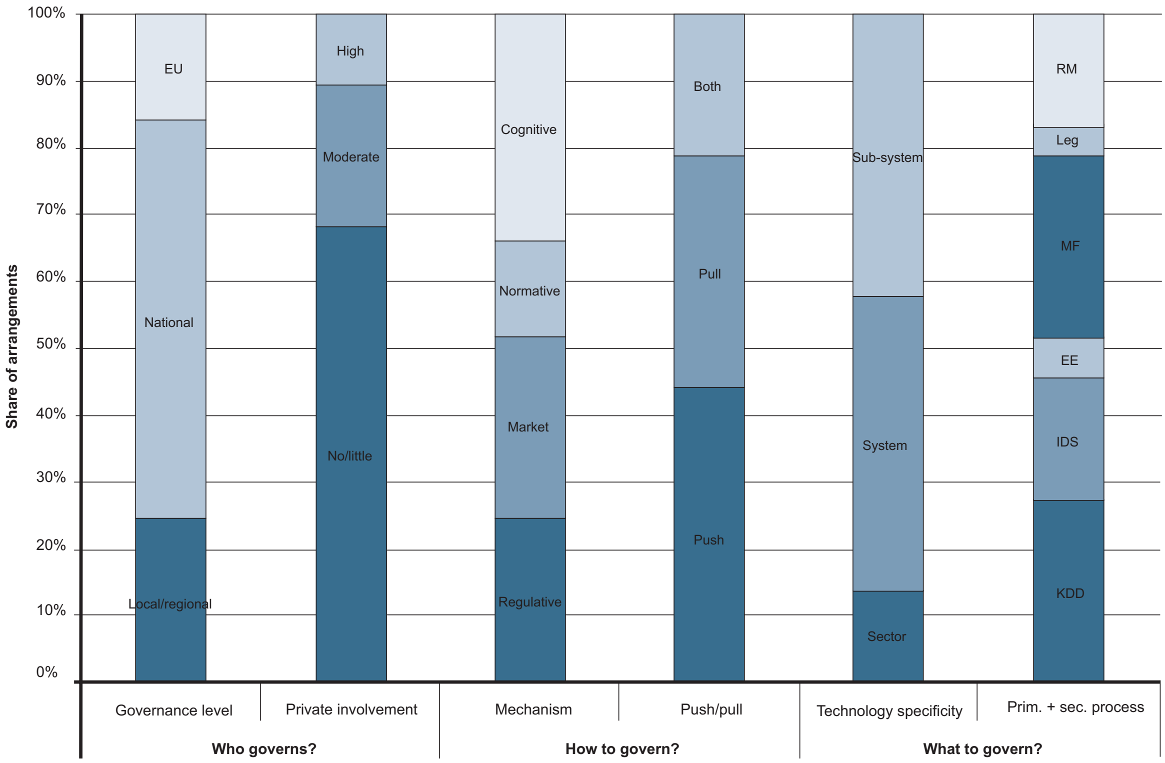

Figure 8: The share of governance arrangements allocated to each alternative for each dimension in Table 10

(KDD = Knowledge Development and Diffusion, IDS = Influence on the Direction of Search, EE = Entrepreneurial Experimentation, MF = Market Formation, Leg = Legitimation, RM = Resource Mobilization).

LIST OF INTERVIEWS

The interviews listed below were performed in 2004-2005 by Karl Hillman (then named Jonasson), Björn Sandén, and Hanna Jönsson at Chalmers University of technology, and in 2009 by Karl Hillman at IMIT.

- Åke Brandberg and Bengt Sävbark, Ecotraffic, 4 Feb 2005
- Magnus Brandel, former State Secretary, 3 Feb 2005
- Per Carstedt, BAFF (BioAlcohol Fuel Foundation), phone 31 May 2005
- Nils Elam, Atrax Energi, 18 Jan 2005
- Sten Flodin, formerly SSEU (Foundation for Swedish Ethanol Development), phone 26 Sep 2005
- Erik Herland, Lantmännen and LRF (Federation of Swedish Farmers), 3 Feb 2005 & 12 May 2009
- Björn Hugosson and Eva Sunnerstedt, Environment Administration, City of Stockholm, 29 Jan 2004
- Olle Hådell, Swedish Road Administration, 25 Aug 2005
- Patrik Klintbom, Volvo Technology, 13 May 2009
- Helena Kock-Åström, City of Linköping, 15 Jan 2004
- Anders Kärrberg, Volvo Car Corporation, 24 Apr 2009
- Jakob Lagerkrantz, Swedish Association of Green Motorists, 4 May 2009
- Ingvar Landälv, Chemrec, 3 Feb 2005 & 12 May 2009
- Göran Lindblå, OKQ8 and OK, phone 8 Jun 2005
- Anders E. Nilsson, Swedish Road Administration, phone 2 Jul 2009
- Krister Nilsson, formerly at the Ministry of the Environment, 11 May 2009
- Magnus Nilsson, Swedish Society for Nature Conservation and T&E (European Federation for Transport and Environment), 11 May 2009
- Bo Ramberg, Fordonsgas ('Vehicle gas'), 20 Jan 2005
- Charlie Rydén, Protima, 4 Feb 2005 & BAFF (BioAlcohol Fuel Foundation) and Sekab, 12 May 2009
- Lars Tegnér, Swedish Energy Agency, phone 20 Sep 2005
- Sören Udd, Volvo Powertrain, phone 28 Sep 2005
- Lars Waldheim, TPS Termiska Processer, phone 25 & 27 Jan 2005
- Stephen Wallman, BilSweden, 29 Oct 2004

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