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Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden

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Supporting the development and diffusion of sustainable innovations has become a dominant topic on the political agenda of many countries. However, this has proven to be a difficult task. To increase insight in such processes, this paper takes biofuel technologies in the mobility sector as the topic of a comparative case study. Various national governments have supported innovation trajectories around biofuels. We analyse, assess and compare two such trajectories as they have developed so far: one in the Netherlands and one in Sweden. A Technological Innovation System (TIS) approach is applied. A TIS is constituted by actors, networks and institutions, that are to be gradually constructed around a technology. We analyse whether governments and entrepreneurs have succeeded in developing seven key processes, or system functions, necessary for the development and diffusion of biofuel technologies. By analysing the build-up of system functions over time we identify virtuous and vicious forms of cumulative causation. The Dutch and Swedish TISs for biofuels are followed from 1990 to 2005. Our comparison shows that, due to the fulfilment of system functions and the emergence of cumulative causation, the Swedish TIS has reached a market expansion and broad social implementation of biofuels, whereas the Dutch TIS has established considerably less.

Keywords: technological innovation systems; system functions; biofuels

1. Introduction

The problem of climate change – as a result of greenhouse gas emissions – is today (2008) seen as one of the most important environmental issues. A major culprit is the transport sector, which has been growing for several decades (IEA 2004). Many scenarios assume that this sector will continue to increase its share of world fuel use for many decades (EIA 2003; IEA 2006). The emissions from the transport sector can be mitigated by a reduction in transport activity and more efficient vehicles, but there is also a need for new sources of energy that – on a net balance – do not (or barely) give rise to greenhouse gas emissions. Thus, strong arguments are made for public support of renewables (Sandén and Azar 2005), and there is an increasing political

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willingness to particularly support biomass-based transportation fuels: i.e. biofuels (IEA 2004). In the European Union (EU), this has been acknowledged in a policy directive, which presses the national governments to enforce the introduction of biofuels (EU 2003).

Still, the task of supporting renewables is not trivial. The emergent technology will have to compete within the environment of a techno-institutional complex: a set of interlinked 'large technological systems and the public and private institutions that govern their diffusion and use' (Unruh 2000, 825–826). Over the past decades, this complex has evolved into an energy and transport system that continuously provides positive feedback – in the form of scale economies, cumulative learning, network externalities and the emergence of habitual routines – for the further development of fossil based technologies (Unruh 2002). Hence, diffusion of emerging renewable technologies is hampered by the momentum of the energy and transport systems.

Nevertheless, change is possible. Studies by Suurs and Hekkert (2005, 2008) and Sandén and Jonasson (2005) have investigated the recent history of biofuels in the Netherlands and Sweden, respectively. Both studies show how the technology passes through a formative stage characterised by weak institutions, little market demand and multiple technology designs. The returns on (private) investments are highly uncertain and only to be expected in the long run – developments largely depend on public support.[2] However, in Sweden, entrepreneurial efforts and government policies linked up in a process of cumulative causation (as a result of positive feedback) (Myrdal 1957) putting significant pressure on the transport system to adopt biofuels, with the result that utilisation increased, starting from the mid 1990s, to more than 2% of the total transport fuel supply in 2004 (Sandén and Jonasson 2005). In the Netherlands, the government also supported biofuels, but market diffusion has – at the time of writing – barely taken off (Suurs and Hekkert 2005, 2008). How can this difference be explained and what lessons can be learned?

The purpose of this paper is to point out the drivers and barriers for cumulative causation in the development of biofuels in both the Netherlands and Sweden (1990–2005). Questions to be answered are:

(1) What patterns of cumulative causation occurred in the two countries?
(2) What caused the patterns to emerge or collapse?
(3) What lessons may we draw for policy makers and entrepreneurs?

One important point to make is that in this paper we are interested in dynamics and growth processes in a formative stage. We do not attempt to say anything about the desirability of introducing various types of biofuels. Obviously, the desirability as perceived by the actors in the system does play a role in our analysis as these positive and negative expectations are crucial to understanding innovation system dynamics. We also admit that in later growth stages, beyond the scope of this study, limitations of various kinds may very well hamper a sustained growth (as a result of negative feedback).

Studying the formative stage of technological trajectories demands an analytical framework that addresses not just the technical and economical dimensions of technological trajectories but also the broader processes of societal embedment (Bijker, Hughes, and Pinch 1987). Moreover, because the formative stage is characterised by rapid changes in the system surrounding and supporting the technology, the analysis needs to pay close attention to the dynamics of change within this system (Hekkert et al. 2007; Jacobsson and Bergek 2004). There are many partly related streams of literature that in different ways take these dimensions into account (Bijker 1987; Van de Ven 1993). In this study we choose to adopt the framework of Technological Innovation Systems (TISs). The TIS approach stresses the idea that innovation is a collective and context specific process, wherein governments have a particular role of facilitating the introduction of emerging technologies (Jacobsson and Johnson 2000). The recent TIS literature that we build upon explicitly tries to conceptualise the dynamics related to a technological field (Hekkert et al. 2007). Much attention has been given to systematic operationalisation of the concepts used (Hekkert et al. 2007), and the system metaphor opens for assessment of system performance and effectiveness of policy and entrepreneurial intervention.

The paper is structured as follows: In Section 2, an overview of theoretical concepts is presented, together with a methodology for operationalising the concept of cumulative causation. Section 3 presents a background to biofuels development, and Sections 4 and 5 provide the analysis of the Dutch and Swedish TISs related to biofuels, here called Biofuels Innovation Systems (BISs). In Section 6, a comparison of the observed dynamics is given, resulting in some strategic insights. Conclusions are formulated in Section 7.

2. Functions of innovation systems

Various innovation system approaches exist: from nationally oriented approaches to those with a focus on regions or industrial sectors. In our case we apply the framework of Technological Innovation Systems (TISs). In terms of its boundaries a TIS can be regarded as 'cross-cutting' geographical and sectoral domains; the principle starting point is a technology field. As an additional delineation we focus on the national TISs of the Netherlands and of Sweden. In the greater part of the literature, the TIS is defined by the actors (organisations), networks of actors and institutions (regulations, norms, cultures) involved in the generation, diffusion, and utilisation of a technology.[3]

The TIS framework serves as a heuristic to point out the structural elements that are relevant for a strategic intervention in technology development (Jacobsson and Bergek 2004).[4] However, most innovation system approaches have focused on just this and, as a result, have neglected the development process itself. See, for instance, how Freeman contrasts various National Innovation Systems – Japan *vs* USSR in the 1970s, East Asia *vs* Latin America in the 1980s – in terms of R&D intensity, educational system, industrial structure, and many other factors (Freeman 1995). Even if processes are being measured, such as yearly budgetary flows or patent outputs, then still no attention is paid to the interdependence of such processes in time.[5] Important contributions to the sectoral innovation systems approach also show a primary focus on the state of structures: technological regimes rather than historical mechanisms (Breschi, Malerba, and Orsenigo 2000). The TIS approach has been recognised by Carlsson et al. (2002) to be the most dynamic member of innovation systems approaches and many scholars have used the TIS framework to conduct longitudinal studies that indicate the key historical drivers of a technological field.

A focus on static structure has some disadvantages: (1) as structural factors have been historically shaped, they will differ so much between contexts that a comparison between TISs is hard to make, and (2) a static structural approach tends to disregard important explanatory factors behind cumulative causation dynamics (Hekkert et al. 2007). To overcome these shortcomings, recent studies have suggested augmenting the analysis of structures with an analysis of key processes, or system functions (Carlsson et al. 2002; Bergek 2002; Jacobsson and Bergek 2004; Bergek et al. 2008; Hekkert et al. 2007; Edquist 2005). The literature presents different lists of such functions. In this paper we will use the seven functions listed in Table 1 (for an overview, see Bergek 2002; Hekkert et al. 2007).

Table 1. Functions of technological innovation systems.

F1. Entrepreneurial activities	At the core of any innovation system are the entrepreneurs. These risk takers perform the innovative commercial experiments, seeing and exploiting business opportunities.
F2. Knowledge development	Technology research and development are prerequisites for innovations, creating variety in technological options. R&D activities are often performed by researchers, but contributions from other actors are also possible.
F3. Knowledge diffusion	The typical organisational structure of an emergent innovation system is the knowledge network, primarily facilitating information exchange.
F4. Guidance of the search	Often within a transition trajectory, various technological options exist. This function represents the selection process that is necessary to facilitate a convergence in development, involving for example policy targets, outcomes of technical or economical studies and expectations about technological options.
F5. Market formation	New technologies often cannot outperform established ones. In order to stimulate innovation it is necessary to facilitate the creation of (niche) markets, where new technologies have a possibility to grow.
F6. Resource mobilisation	Material and human factors are necessary inputs for all innovation system developments, and can be enacted through e.g. investments by venture capitalists or through governmental support programmes.
F7. Support from advocacy coalitions	The emergence of a new technology often leads to resistance from established actors. In order for an innovation system to develop actors need to raise a political lobby that counteracts this inertia, and supports the new technology.

These functions are defined as being categories of ‘actions taken by actors in the system’ (events).[6] Since the system functions are defined on a more abstract level than the actions themselves, they are applicable to a wide variety of empirical observations. As a result, it becomes possible to compare different TISs in a systematic way. The system functions can be used to explain the endogenous dynamics of the system. However, any TIS is also embedded in a wider environment that influences these dynamics. This exogenous impact consists of factors beyond the direct influence of the national TIS, for instance oil price shocks and international policy.[7]

At the heart of the TIS approach is the idea that system functions can interact with each other (Bergek et al. 2008). For instance, the successful realisation of an important research project (knowledge development), may result in a rise of expectations among policy makers (guidance of the search), which may subsequently trigger the start-up of a subsidy programme (resource mobilisation) to support even more research projects (knowledge development). This example illustrates how complementary effects can result in the unfolding of a pattern of cumulative causation (Myrdal 1957).[8] Events drive other events that in turn set in motion new events. As the sequence continues, it can branch out, eventually resulting in a richer realisation of system functions. Ideally, these dynamics may be cyclic, creating a loop of positive feedback, which may trigger a take-off from a formative to a growth stage of the TIS. However, positive feedback may also be destructive, yielding a regression of the TIS. In the first case we speak of virtuous dynamics (a build-up sequence) and in the second case of vicious dynamics (a break-down sequence).[9]

The empirical basis for the analysis of the TIS dynamics is a narrative consisting of sequences of key events.[10] Each event is mapped on a system function; this way the event serves as the empirical counterpart of a system function (Table 2). Patterns of events in the narrative can provide insight in the emergence of cumulative causation. Identification of patterns is based on

Table 2. Event types as indicators of innovation system functions; some events may contribute negatively to a system function (for instance expectations or lobbies).

System function	Event types
F1: Entrepreneurial activities	Projects with a commercial aim, demonstrations, portfolio expansions
F2: Knowledge development	Studies, lab trials, pilots, research programmes
F3: Knowledge diffusion	Conferences, workshops, alliances between actors
F4: Guidance of the search	Expectations, promises, policy targets, standards, research outcomes
F5: Market formation	Market regulations, tax exemptions, events constituting niche markets
F6: Resource mobilisation	Subsidy programmes
F7: Support from advocacy coalitions	Lobbies, advice

qualitative techniques presented in Poole et al. (2000). Here our focus is on interaction patterns, i.e. sequences of events. By relating event sequences to the abstract level of system functions, we can point out how system functions reinforce (or antagonise) each other through time. If this carries on for some time, this indicates a process of cumulative causation.[11]

The narratives are organised chronologically in episodes, where all episodes are characterised by different types of interaction patterns. When an event contributes to a system function, this is indicated within square brackets and numbering following Table 1 [F*x*]. A negative contribution is indicated by a minus sign [–F*x*]. Common background factors are introduced in the following section; exogenous factors that are case specific are only mentioned in the separate narratives.

3. Background to biofuels development

We identified five exogenous factors that drive or hamper the endogenous developments in both our cases: (1) oil supply, (2) local air and water quality, (3) EU agricultural policy, (4) climate change, and (5) technology features. These factors are of both international and national origin, but are common for both countries and are generally unaffected by the specific Biofuels Innovation Systems (BISs). As will become clear from our analysis, their influence on BIS dynamics differed between the two studied systems.

The first factor is the insecurity of oil supply, mainly represented by oil price shocks. The oil crises in the 1970s made the industrialised world aware of the vulnerability connected to oil dependence. Alternative energy sources were sought and increasingly biofuels technologies were being developed to utilise them. However, from the 1980s on, the oil price dropped and ceased to be a driver of change. Cheap fossil fuels then became an economic barrier for all renewables development. This only changed towards the end of the studied period, as the oil price began to increase.

The second factor concerns worries about local air and water quality. The issue arose on the political agenda throughout Europe from the 1980s on. In the transport sector this resulted in incremental innovations such as the catalytic converter and cleaner diesel engines. It also became an argument for implementing biofuels.

Third is EU agricultural policy. The issue at hand is a restructuring of the declining agricultural sector, reducing the agricultural surplus and exploiting new markets. From the 1990s, farmers received subsidies for keeping fallow grounds and for the cultivation of non-food crops. The climax was the 'Biofuels Directive' of 2003, in which targets were set for the member states regarding the introduction of biofuels.[12] The directive was increasingly legitimated by referring to energy security and climate change.

Fourth, the debate on climate change especially gained attention in the 1990s. Because of the possible reduction of CO_2 emissions, biofuels were seen as an interesting option. A milestone was the signing of the Kyoto treaty by the EU member states in 1998. The European Commission recognised the utilisation of biomass resources as having a great potential to reduce CO_2 emissions (EU 1997).

Finally, in addition to these factors, different technologies emerged of which the inherent features were affecting the events in our two cases. European policy has particularly supported biofuels based on agricultural products. This involves a rather conventional set of conversion technologies with limited performance in terms of costs and CO_2 reduction. An alternative exists: a second technology group with potentially lower costs and higher CO_2 reductions (Hamelinck and Faaij 2006). The differences between this first generation (1G) and second generation (2G) of biofuels have played a central role.[13]

In the following we will reconstruct the development of the Swedish and the Dutch BISs. For each country we will focus on that part of the technological domain where the most activities have taken place; 1G/2G bio-diesel in the Netherlands, and 1G/2G bio-ethanol in Sweden.[14]

4. The Dutch Biofuels Innovation System: the case of bio-diesel

Developments of biofuels for transport started around 1990. The case of diesel substitutes serves to illuminate the characteristic features of this development. Four episodes are distinguished.

4.1. *European drivers of change*

Developments of transport fuels started when, from 1990 on, small entrepreneurial experiments with the adoption of 1G biofuels were initiated [F1]. The projects received policy support and financing, partly from the EU (exogenous). Trials were performed [F2] and turned out to be technically successful [F4], but the economic returns were disappointing [–F4]. Regional governments played a guiding role during this early start [F4]. However, the national government stood back, as it doubted the importance of the small projects [–F4]. Moreover, a couple of influential assessment studies [F2] underlined the shortcomings of the agriculture-based 1G biofuels [–F4]. The argument was that they were expensive and offered no long term potential (*Algemeen Dagblad* 1992; *NRC Handelsblad* 1992).

Up to 1995 not much happened. In this first episode, developments were mainly driven by the EU policy which was being prepared (exogenous). The system functions were just beginning to take shape.

4.2. *The shaping of a niche*

The experiments with the adoption of agriculture-based fuels had limited success. A major drawback was the extreme scarcity of land, which pushed up the production costs of the energy crops (Landbouw-Economisch Instituut 2005). In contrast, another exogenous factor triggered a wave of new experiments, namely the increased stringency of regulation with respect to local water quality standards. Biofuels became a commercially feasible option for the utilisation in ships, as they are biodegradable and therefore less polluting.

A small niche market emerged [F5]. Two (private) boating companies in the rural province of Friesland grasped the opportunity and initiated projects with 1G bio-diesel [F1]. The companies started adoption trials [F2]; as they did this, they turned to government authorities, on the provincial and on the national level, to lobby for a tax exemption [F7]. The province – and the district board of agriculture – supported the idea and started to advocate biofuels as well [F7]. They were successful; a first tax exemption – for two years – was provided [F5] (*Het Financieele Dagblad* 1995).

The adoption experiment [F1] resulted in knowledge creation [F2] and most importantly it served as an example to others in the field [F4]. The province decided to adopt bio-diesel itself as well, for its fleet of service boats [F1]. Multiple other boating projects were started [F1]. Again tax exemptions were demanded [F7], and were in turn issued by the national government [F5]. The 1G technologies gained more and more attention [F4]. Still, the experiments were only partly successful; technically everything seemed to work, but the boats caused a smell and there was a negative economic pay-off [–F4]. Nevertheless some of the experiments continued till 2002 [F1].

The entrepreneurial (boating) experiments contributed to a first wave of cumulative causation, driven by advocacy coalitions of entrepreneurs and local governments and their consistent lobby for resources. This was exogenously conditioned by local water quality regulations.

Meanwhile, developments around 1G biofuels were heavily scrutinised by scientists, engineers, and most notably, by the environmentalist movement [–F4, –F7]. The national government remained divided, and as a result, entrepreneurs who performed adoption experiments [F1, F2] lacked the necessary support. Tax exemptions [F5] were incidentally issued, though for a short time period. No policy strategies were formulated, and hence (potential) bio-diesel entrepreneurs remained in the dark with respect to the future institutional support [–F4].

From 1997 the criticism on biofuels – aimed at 1G technologies – turned into a more positive movement as new options gained attention. From then on, the 2G technologies – which were being developed in the laboratories [F2] – became part of the public discussion [F4]. This was mainly the work of entrepreneurs who started attempts to bring 2G biofuels to the market [F1]. The Dutch government – mainly the ministry of VROM (the Ministry of Housing, Spatial planning and the Environment) – considered acquiring a stake in this promising emerging technology [F4].[15]

So 2G biofuels were starting to play a role during this episode, although this was largely limited to knowledge development. A downside was that now the experiments with 1G biofuels were shaded by the promises of 2G biofuels. No new entrepreneurial experiments were initiated.

4.3. *The GAVE programme initiates R&D*

In 1998 the climate issue became an important exogenous driver. As a response to the Kyoto protocol, the GAVE (Gasvormige en Vloeibare Energiedragers) platform is initiated in 1999 – through Novem.[16] The programme was the first programmatic government attempt to support biofuels [F4]. The transport sector was originally not its specific orientation, but transportation fuels were quickly established as a priority.[17] GAVE's first move – during 1999 – was to authorise a number of assessment studies [F4, F6] (GAVE 1999; KEMA Consultancy 2000). The studies should clear up the controversy around various biofuel options. The result was a shortlist of fuel chains to be analysed in more detail, based mainly on energy balances and cost figures [F2]. GAVE's advice was to exclusively support the projects where a CO_2 reduction of 80% was guaranteed possible [F4].[18] All 1G options were then (*de facto*) excluded from further assessments [F4] (GAVE 2003). It is within this context that the term 2G biofuel was actually introduced to distinguish the contested agricultural biofuels from technologically advanced options.[19]

GAVE provided €2 million [F6] to stimulate the formation of networks [F3] and to support assessment research [F2]. This would eventually lead to a demonstration for which a budget of €5 million was reserved [F6]. The emphasis was on innovation in fuel production, where cooperation with downstream industrial parties and private investors was encouraged [F3]. The projects that started [F1] were all exclusively oriented towards 2G options.

The projects were setup by two alliances – the Shell–ECN network[20] and the TNO network[21] – and other actors, among which were investors [F6], a car company and many others [F1, F3] (GAVE 2002). The projects were successful [F4], particularly with respect to solving important technical bottlenecks [F2] such as gas cleaning [F2] (Boerrigter, Den Uil and Calis 2002). The programme served as a catalyst that bundled and guided R&D projects that until then had been going on in relative isolation [F3, F4]. As a consequence multiple entrepreneurs [F1] started new biofuels projects during this episode, even outside GAVE.

The purpose of GAVE was to realise a demonstration plant. By the end of 2002 it turned out that the two networks were both viable candidates. Unfortunately both parties decided to decline [−F1]. As a result, the programme stopped [−F6] and failed to deliver. The main reason was that the building of a commercial plant would cost far more than €10 million; with the absence of a flanking market creation policy, this did not make an economic business case.

In this episode, a pattern of cumulative causation pivoted around entrepreneurial experiments related to 2G technology, but especially around guidance, knowledge diffusion and resource mobilisation delivered by GAVE. This has resulted in important successes. Knowledge has been developed and the urgency of developing sustainable transportation fuels was beyond discussion, but still there was no commercial perspective for biofuels. Besides the deficiencies of the national BIS, the slow progress with 2G biofuels can to some extent be seen as an exogenous factor, i.e. the requirements for advanced technology.

4.4. *A market driver*

Things changed in 2003 as the EU issued the Biofuels Directive (EU 2003). This exogenous factor had drastic consequences, as in contrast to the Dutch government, the EU was largely oriented towards 1G biofuels. With the subsidy programme terminated and with the new task of translating the EU directive to national policy, the national government reoriented its policy (Stromen 2003).

From 2003 on, GAVE was given a new priority task [F4]: the development of a generic market for biofuels. The 1G technologies were increasingly perceived as bridges towards 2G fuel implementation.[22] The 1G bio-diesel options had so far been excluded from support by GAVE [–F4], with reference to arguments such as high costs and weak environmental performance, implying that market-oriented projects had been subdued. Up to 2002, not a single drop of bio-diesel (1G or 2G) had been produced by Dutch companies.[23] By 2002–2003 this changed, as many regional entrepreneurs executed plans for the construction of small factories [F1]. The main driver was (again) the EU directive (exogenous).

These were the first commercial experiments that targeted the supply side of the biofuels chain [F1]. The projects were supported by a large number of actors; among them farmers, farmers' associations and local government authorities [F3]. Many of these actors were made shareholders [F6]. Also, biofuels were promoted to potential users [F4]. For these projects to work out financially, tax exemptions were requested [F7], and issued on a project basis [F5] (*Bizz* 2002a,b). By 2005, the first (1G) bio-diesel plant was built. This successful outcome [F4] triggered a pattern of cumulative causation, as from 2002 numerous projects [F1] started all over the country, especially in rural areas. The later developments were additionally driven by the

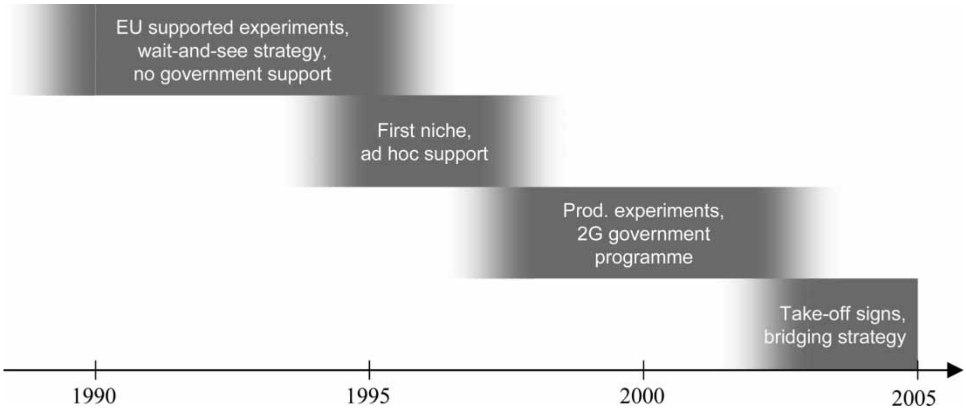

Figure 1. Four episodes of Dutch BIS development.

advocacy and guidance from the Energy Valley cluster [F7, F4], a regional network of public–private partnerships. The first plant became an often used example [F4] (*Dagblad van het Noorden* 2004, 2005; *Leeuwarder Courant* 2005; *Provinciale Zeeuwse Courant* 2004). In 2004 numerous municipalities started to adopt bio-diesel for their car fleets [F1] (Stromen 2004; Rotterdams Dagblad 2004).

In this period, multiple functions were fulfilled – bottom–up – by various collaborating actors. The promise of the (exogenous) EU directive had apparently been more important in fostering this interaction pattern than the ad-hoc national support. Remarkably, it was again regional authorities and entrepreneurs that took the BIS forward. The perspective of a market, offered through the EU directive, played a pivotal role. Also national policy makers realised that their scheme towards demonstrating fuel chains had failed because there was no market. In accordance with this, GAVE changed its role from an R&D catalyser to a facilitator of networks and markets. In the process, GAVE influenced guidance by stressing the concept of bridging technologies – from 1G to 2G. In summer 2004, the government released a white paper on traffic emissions. The document contained a section on generic measures to be taken for the implementation of biofuels. The 1G fuels were now explicitly regarded as a bridging option. Whether this will turn out to be a watershed event, leading to a take-off remains to be seen. See Figure 1 for an overview of the four episodes of Dutch BIS development.

5. The Swedish Biofuels Innovation System: the case of bio-ethanol

The development of alternative fuels in Sweden began in the 1970s with a large focus on methanol produced from different resources. This was a response to drastic increases in the oil price, but the interest faded out as the price went down in the early 1980s. At this time, the first activities related to bio-ethanol surfaced. Through the years, this development would come to revolve around four parallel tracks that were more or less intertwined and in different ways contributed to the build-up of the BIS. These were the bus niche, the production of wheat ethanol (1G), the market for flexifuel cars and wood ethanol research (2G). The Foundation for Swedish Ethanol Development (SSEU) was the central player in two of them, while partly influencing the other two. It was formed in 1983 by private and municipal companies around a plant processing by-product ethanol from the *pulp and paper industry in Örnsköldsvik. After 1990, bio-ethanol became the dominating biofuel. It serves as an illustrative example of the development of biofuels in Sweden, during six episodes.*

5.1. *1980s pre-developments*

After some lobbying efforts [F7], the Federation of Swedish Farmers (LRF) gained financial governmental support [F6] to run a pilot plant for 1G production during the first half of the 1980s [F1, F2]. In parallel, the existing production in Örnsköldsvik was supported by the government for reasons of national security of supply of chemicals (exogenous). New markets were however sought for economic reasons [F1].[24] Inspired by international developments in the field (exogenous), the focus of SSEU was to promote the use of ethanol from biomass for transport [F7]. The diversity of actors involved in SSEU [F3] resulted in the vision of 1G bio-ethanol being a bridge to the more advanced 2G bio-ethanol [F4].[25] However, voices were raised that it would be cheaper (and more efficient) to produce methanol instead of ethanol from wood [–F4].

During the second half of the 1980s, SSEU took the initiative for a field test with two ethanol buses in Örnsköldsvik [F1, F2], and then a larger fleet demonstration in Stockholm [F1, F2]. The Stockholm project was performed in co-operation with the bus manufacturer Scania and the municipal Stockholm Public Transport [F3], but was also financed by the government [F6]. Two exogenous driving forces were present in the project; air pollution, and a possible international market for Scania's ethanol buses.[26]

In general, entrepreneurs and advocates played an important role in this early stage, where a first interaction pattern already could be seen between advocacy support, resource mobilisation, entrepreneurial activities and knowledge development.

5.2. *Bus market formation and 2G R&D*

A government bill on energy policy (Swedish Ministry of Industry 1991) – the 'Three-Party Agreement' – paved the way for further expansion [F4], and two R&D programmes followed from the agreement. First, the Ethanol Research Programme [F4], which included financial support [F6] for R&D of production processes for 2G wood ethanol, mainly performed at universities [F2]. Second, the KFB (the Swedish Transport and Communications Research Board) Biofuels Programme [F4] funded projects between 1993 and 1997 [F6]. The aim was to test and demonstrate the use of ethanol as a transport fuel [F2], which implied that the ethanol bus projects were brought up to a national level [F3] and in parallel a market for ethanol city buses evolved in Swedish municipalities [F5]. The tests were performed by universities, companies and municipalities around Sweden [F1, F2], often as joint projects [F3]. The first projects of the Biofuels Programme came from a list prepared by SSEU [F7] (Arnold and Thuriaux 1997).

The development was stimulated by exogenous factors – the growing interest for environmental issues in the municipalities and concerns for air quality.[27] In Stockholm and other larger cities, 'clean vehicle organisations' were formed to manage field tests of electric cars – an exogenous factor that later turned out to be useful for the diffusion of 'clean vehicles' in general, including those running on bio-ethanol.

This episode was strongly connected to the ongoing advocacy support from LRF and SSEU. Supplemented by guidance and funding from the government, the interaction pattern related to buses in the previous episode was repeated in other municipalities, indicating cumulative causation. Fulfilment of system functions diverged gradually and even a first market started to form.

5.3. *EU entrance and tax exemptions*

Thus, when Sweden entered the EU in the middle of the 1990s, there were already some structural elements in place in the national BIS, both regarding supply and end-use technologies. The federation of Swedish Farmers (LRF) had been planning to build a 1G bio-ethanol plant to market surplus production [F1] ever since the pilot plant was closed down in the mid 1980s [–F1]. It lobbied for better economic conditions for bio-ethanol production [F7], which were finally rendered possible as the result of the Three-Party Agreement [F4]. However, the expansion of ethanol from agricultural crops was delayed owing to Sweden's entrance into the EU, an important exogenous event. The incentives for wheat ethanol production decreased because of EU subsidies for export of agricultural surplus (exogenous). In addition, tax exemptions for biofuel pilot projects needed approval from the EU.[28]

In 1997, an application [F7] for specific tax exemptions [F5] for the planned 1G bio-ethanol plant was approved by the Swedish government [F4], and the following year it was approved as a pilot plant by the EU. A contract on low blending was arranged with the fuel distributors [F5] and the plant was built by LRF [F1]. Production started in 2001.

The main connection to the previous episode came with the guidance from the Three-Party Agreement and the ongoing advocacy support by LRF. Also in this episode, the entrepreneurial function was crucial, leading to guiding decisions and even market formation. However, there was also an important hampering influence from the exogenous EU level.

5.4. *Enlarging the BIS to include cars*

For non-fleet vehicles, which are not belonging to a common depot, there was a problem that no ethanol pumps were put up if there were no ethanol cars, while no such cars could be sold if there were no pumps. Backed by SSEU,[29] the former leader of the ethanol bus project in Stockholm and a car retailer from Örnsköldsvik decided to tackle this 'chicken and egg' situation by importing flexifuel cars[30] from Ford in the US [F1]. The project was gradually expanded from 3 to 300 vehicles [F1], including an increasing involvement of the fuel distributor OK [F5].[31] The flexifuel introduction, which was partly funded by the KFB programme [F6], was successful in demonstrating that it was possible to use ethanol also for non-fleet vehicles [F2]. The cars were sold with mainly environmental arguments [F4]. In 1998, the flexifuel importers acquired the task from Clean Vehicles in Stockholm and the Swedish Energy Agency of organising a larger purchase of a new generation of flexifuel car, resulting in the introduction of Ford Focus flexifuel in 1999 [F5].[32]

This is perhaps the clearest example of how entrepreneurs set out to build up parts of the BIS that were lacking from previous episodes. Cumulative causation related to buses was now repeated for cars, with some actors (SSEU, the City of Stockholm and KFB) still involved. This was the start for a larger expansion of the use of 'clean vehicles' in Sweden.

5.5. *R&D programmes and large-scale strategies*

An ambition to create 'a green society' was pronounced by the Prime Minister in 1996 [F4]. After this, the ethanol research programme was followed up by a new one [F4], to be pursued during 1997–2004, including enlarged funding [F6] for 2G bio-ethanol R&D [F2] (Swedish Ministry of Industry and Trade 1997). In addition, a programme co-funding environmentally related investments [F6] was introduced by the Swedish Environmental Protection Agency [F4]. This contributed with funding for the later stages of the ethanol flexifuel introduction [F6].[33]

At the end of the 1990s, two exogenous factors were strengthened – climate change and rising oil prices. As a consequence, in Sweden, increasing legitimacy was seen for efficient large-scale solutions for transport fuels (e.g. gasification technology), which implied that 1G biofuels were being questioned [−F4]. Despite this controversy, there was also co-operation in lobbying for bio-ethanol in general, between advocates of 1G bio-ethanol and advocates of R&D of more efficient, 2G bio-ethanol production [F7].

In 2002, four governmental agencies (VINNOVA [Swedish Agency for Innovation Systems], Swedish Energy Agency, Swedish Environmental Protection Agency, and Swedish Road Administration) agreed on a common strategy for the introduction of biofuels, where production of 2G bio-ethanol was to be – demonstrated by building a plant – [F4]. Blending of biofuels was generally preferred to the use of pure fuels, which would have to be used where they were 'economically feasible' [F4] (Eriksson et al. 2003).[34] Following this strategy, the two ethanol research programmes were followed up by a 2G pilot plant [F2], built in Örnsköldsvik. It started production in 2004, and was mainly financed by the Swedish Energy Agency [F6].[35] Though a 1G technology, wheat ethanol also survived the discussion on large scale solutions and was recommended for blending into petrol in the four agencies' strategy document [F4].

Cumulative causation was here mainly related to 2G bio-ethanol R&D. Building on previous episodes, guidance of the search was followed by resource mobilisation and knowledge development. In addition, despite the criticism, 1G bio-ethanol was still present because important system functions had been established in its favour.

5.6. *Large scale market stimulation*

Despite the criticism of 1G fuels, beginning around 2000, various economic incentives were introduced for biofuels and 'clean vehicles', such as reduced vehicle tax and lower benefit tax for privately used company cars on the national level [F5], and parking fee subsidies on the local level [F5]. General exemptions from energy and CO_2 tax for biofuels were decided upon [F5], which contributed mainly to the 5% blending of bio-ethanol in the petrol sold in Sweden (Swedish Ministry of Finance 2006). In parallel with the Swedish 1G production, the import of ethanol produced from sugar cane in Brazil was rapidly increasing (Swedish Board of Agriculture 2006).

The Swedish policies for market stimulation were further justified through the EU Biofuels Directive, and national targets were set [F4]. 'Clean vehicles' were exempted from the congestion tax in Stockholm during the trial [F5], and some national and local authorities were obliged to purchase certain shares of 'clean vehicles' [F5]. To guarantee the build-up of a refuelling infrastructure, there was a political agreement that an increasing number of filling stations should supply at least one renewable fuel, which would mainly imply bio-ethanol [F5] (Swedish Ministry of Sustainable Development 2005). Together the various measures contributed to a rapid expansion of the market for flexifuel cars and the introduction of several new models [F5].

This episode was characterised by the strengthening of the market formation function, but also – following from the new economic incentives – resource mobilisation. The emergence of these functions, however, was a result of the variety of system functions built up through cumulative causation in the previous episodes. Most system functions were strong and a take-off was awaited for domestic bio-ethanol production, though sometimes criticised mainly for economic reasons. 2G bio-ethanol was several years ahead, and would have to compete for R&D resources with

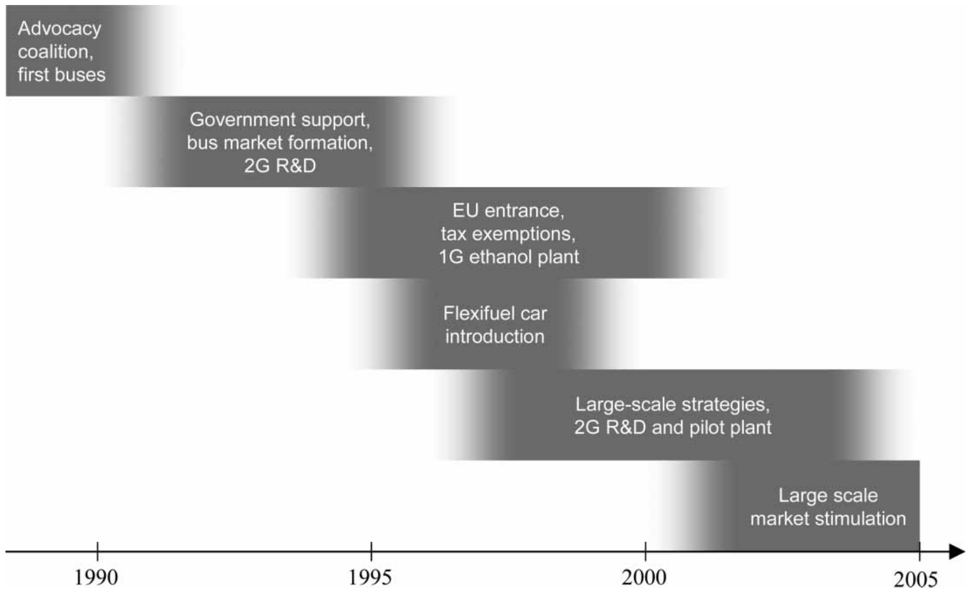

Figure 2. Six episodes of Swedish BIS development.

other 2G technologies (mainly gasification). See Figure 2 for an overview of the six episodes of Swedish BIS development.

6. Comparing the Dutch and the Swedish cases

Our cases show that Sweden and the Netherlands differ significantly regarding the development of their respective BISs. The event sequences portrayed have revealed that in the Dutch BIS, the system functions were fulfilled more or less sporadically and that cumulative causation occurred only for relatively short periods. It could be argued that since the 2003 EU directive this is changing. All system functions are present and seem to increasingly reinforce each other. In Sweden, signs of cumulative causation could be seen already at the onset of the 1990s. Since then most system functions have undergone a continuous positive development. So there are significant differences between the two countries, implying important lessons for BIS actors, such as policy makers and entrepreneurs.

6.1. *Addressing multiple system functions*

As suggested by the TIS framework, our cases confirm the importance of addressing the whole range of system functions. Policy measures are more effective when designed to target all the BIS functions, but also entrepreneurs are most successful in bringing about change when actions are directed at facilitating multiple system functions at once. This is actually what makes cumulative causation possible. Our two cases clearly differ in this respect – especially with regard to policy.

The Dutch government has shown a rather linear orientation to the promotion of biofuels. From the moment that support of 2G biofuels was deemed desirable as a policy strategy, the government has been focusing on subsidising R&D and the formation of networks, but the market was left largely unaddressed. Even the influential GAVE programme lacked attention to market formation. This was – at least partially – the reason for the discontinuation of entrepreneurial activities in the form of a commercial demonstration of 2G biofuels. The possible advantage of a broader policy orientation is shown by the variety of actions taken by the Swedish national government. Besides guidance, Swedish policy targeted knowledge formation, but also – in a more parallel approach – the early entrepreneurial experiments and the (niche) market activities around 1G biofuels. This was partly done by providing financial support but also by means of market stimulation. Influential initiatives are the bus projects supported by the KFB programme, tax exemptions for 1G bio-ethanol, and economic incentives related to vehicle purchase and ownership.

However, the orientation of Swedish policy was as much a result of, as a cause for wider BIS dynamics, and not completely intentional and strategic. Entrepreneurial activities and the formation of advocacy coalitions had a significant impact on policy making.

6.2. *The crucial role of entrepreneurs*

The TIS framework recognises the importance of entrepreneurs through the existence of an explicit function to map their activities. Though various system functions were involved in the realisation of interaction patterns in both countries, our analysis suggests that entrepreneurial activities played a crucial role in stimulating such dynamics. For most occurrences of cumulative causation at the early stages of development related to 1G, the private and municipal entrepreneurs have been prime movers, contributing to the build-up of support from advocacy coalitions, guidance of the search and other functions of the BIS.

In the Netherlands, cumulative causation has generally been short lasting, but where it occurred, it was driven by entrepreneurs. This, for instance, is true for the episode wherein Dutch boating companies started adoption experiments, raising expectations and lobbying for government support. Such activities drew in even more entrepreneurs. Also in Sweden, entrepreneurial activities around ethanol were often the start of a chain of interrelated activities. The first examples are the ethanol bus projects that started before 1990 in Örnsköldsvik and Stockholm, which opened up for further developments towards a market for ethanol city buses. A few years later, similar projects were run in the car segment, partly by the same entrepreneurs. Entrepreneurial activities (of LRF) were also a premise for the building of a 1G bio-ethanol plant.

6.3. *Reducing long-term uncertainty*

So, the entrepreneurial activities play a central role in both countries, but these alone cannot provide enough momentum. As initial policy measures were made possible by entrepreneurial activities, the continuation of entrepreneurial activities was strongly related to the presence of policy support. Our cases show that follow-ups on entrepreneurial activities were strongly related to the presence of consistent government policy. Strong programmatic policy guidance, reducing long-term uncertainty, had a sustaining effect, while the absence thereof was a recurring barrier.

Especially in the Netherlands, the absence of clear policy guidelines made promising entrepreneurial activities too risky to continue (Shell, TNO). Policy makers surely did make contributions to the fulfilment of other system functions – such as resource mobilisation (R&D subsidies) and market formation (tax exemptions), but these were not part of a general policy programme. A positive example is the programmatic support by the national GAVE programme, which strongly influenced a variety of entrepreneurs, especially around 2G technologies. The importance of guidance of the search becomes even clearer from the Swedish case; here, an important decision was taken very early, through the Three-Party Agreement in 1991. Support for ethanol use was warranted, paving the way for R&D programmes and a scaled-up use of ethanol buses. The agreement also resolved the long-standing uncertainty for 1G bio-ethanol production. Another important example is the strategy document elaborated by four governmental agencies in 2002, where a demonstration plant for 2G bio-ethanol and blending of biofuels into petrol (and diesel) was recommended. Both these Swedish examples were strongly related to functions already present in the national BIS.

In both countries the influence of policy programmes – positive or negative – has been crucial. When the government issued consistent policy guidelines, entrepreneurial activities were initiated that fostered further event sequences – and cumulative causation – in the BIS. So, the absence of a consistent policy guidance seems to result in a BIS dominated by uncertainty, with a destructive effect on further experimenting within the emerging technology field.[36]

6.4. *Policy support at different levels*

Our cases show that policy support can – and should – be provided at different levels, i.e. the regional, the national, or the EU level. In both countries the regional level has been important as a source of market-directed innovation. The earliest entrepreneurial experiments were – in several cases – related to regional companies that were strongly linked up with municipality or province. As regional initiatives were connected, a knowledge-oriented industry cluster emerged, but most importantly also advocacy coalitions that pressed national government for policy measures and legislative change. In the Dutch case this became most apparent through the coalition around 1G biofuels in the rural areas. In Sweden, the two first ethanol bus projects were started at the local level. The response from the national government level to these 'niche' dynamics has been very different in the two countries. The Swedish BIS was strengthened through a mostly facilitative orientation, fostering the regional developments and thereby contributing to the build-up of cumulative causation. In contrast, the Dutch government largely neglected support of all developments around 1G, which were mainly driven by regional interests.

An important difference also lies in the countries' relation to EU policy. In the Netherlands, national policy has been largely driven by EU incentives, though mostly it was lagging behind. As a result, the regional projects were typically stimulated by EU policy, while hampered by (the lack of) national policy. Conversely, in Sweden, the national government took the initiative of providing guidance, while the entrepreneurial activities related to 1G fuels – in the beginning of the 1990s – were held back because of the EU entrance and the change in agricultural policy. The developments were continued nonetheless, and years later – when the EU directive was launched – introduction of biofuels had already started in Sweden.

This shows the importance of support from different policy levels, but also that conflicting signals at different levels become a barrier for further developments. Where policy on the national level is lagging behind, coordinated incentives on the regional and the EU levels may stimulate national developments. Where national government shows higher ambitions, the EU policies can be troublesome.

6.5. *Hard technological choice*

From the above, we see that policy makers have been influential in framing the selection environment for biofuels technologies, both in a positive and a negative sense. Our comparison shows how the more fruitful situations were those where national policy allowed for various technologies to develop in parallel, taking into account their respective stage of development. When hard technological choices were made by policy makers, important system functions were weakened.

Government authorities in the Netherlands have been closely involved in the discussion on the technology features themselves. The 2G technologies have been presented as the group worthy of (programmatic) support, while the 1G technologies were left to the market. This way a large part of the BIS was excluded already at an early stage of development. The idea of 1G fuels being bridging technologies to 2G only comes with the implementation of the EU directive. In Sweden, there have been advocates representing either 1G or 2G alternatives, or both, whose standpoints were taken up in the policy-making process. The potential controversy between 1G and 2G was played down because of the resulting governmental support for a variety of alternatives at different stages of development.

Though this idea was not explicitly articulated by policy makers, the Swedish case suggests that cumulative causation was largely facilitated through activities related to the field of 1G bioethanol, where entrepreneurial activities were abundant. Also the most recent Dutch developments show that the technically less promising biofuels should not be underestimated with respect to their potential impact on cumulative causation. A direct selection on behalf of the government towards (primary) technological features yields the risk of killing off a potential for the future.[37]

7. Conclusions

Our analysis partly confirms and explains results suggested in earlier literature. However, applying the framework of Technological Innovation Systems (TISs) to the field of biofuels adds new evidence to the understanding of how emerging technologies develop under the influence of endogenous (and exogenous) forces of change. In addition, some specific lessons on biofuels can be drawn for policy makers and entrepreneurs from our comparison of two Biofuel Innovation Systems (BISs).

Taking a step back, looking at what we have learned, we can conclude that our analysis pointed out the crucial importance of dynamics when trying to understand innovation processes around technologies in a stage of emergence. We adopted the TIS framework to determine the factors that influence such processes, by analysing systematically the build-up of system functions over time. This made it possible to pinpoint how system functions interact and may lead to cumulative causation. The comparative angle allowed us to show similarities and differences from which important lessons could be derived for influencing and improving such processes in the future.

We have particularly shown how the Netherlands and Sweden differed in stimulating the build-up of a comprehensive set of system functions, necessary for the successful development of their respective Biofuels Innovation Systems (BIS). As a result of a continuity in the sequence of various entrepreneurial experiments and the emergence of cumulative causation, the Swedish BIS has reached market expansion and social implementation of biofuels, whereas the Dutch have so far established considerably less. This could only be explained to a limited extent by exogenous factors, suggesting the importance of endogenous forces – system functions – in stimulating BIS dynamics.

The TIS framework can be valuable for policymakers, but also for entrepreneurs. As long as they are active in supporting an emerging technological field, the research results may provide them with strategies to accelerate the build-up of the TIS of which they are part. (Of course, if they want to block this build-up, the results are also useful.)

For instance, both in the Netherlands and Sweden, entrepreneurial activities proved to be a crucial function as a prime mover, triggering cumulative causation. A most important difference between the two countries refers to the system function of guidance. Our study suggests that to reduce uncertainty and to provide for continuous entrepreneurial activities, policy makers, at multiple government levels, should give clear signals of desired developments and intended support programmes. Governments should not pick winners at an early stage of development, but facilitate TIS development. This can only be done by targeting multiple system functions simultaneously, implying a broad policy approach, not just aiming towards a single technology or a single part of the TIS (R&D or market). Entrepreneurs may contribute themselves by forming advocacy coalitions to provide better articulation towards governments of what they believe is desirable or feasible, but should also direct their actions at various system functions.

Some limitations should be expressed as well. Our approach uncovers particularly the dynamics that are endogenous to the technological field. Some macro-events are taken into account as exogenous forces of change. However, many differences at the macro-level between the two countries with regards to cultural, industrial and political structures and events have not been considered as possible alternative explanatory variables.

A second limitation concerns the methodology used. Since it is only in retrospect that we can acquire an insight in the consequences of particular (sequences of) events, it remains difficult to provide truly generalisable lessons. Still, this limitation is not unique to this approach but an inherent feature of social science. We see our ambition to systematise narratives, or history, using the model of a system with functions, to be in line with Freeman and Louçã's plea for reasoned history (Freeman and Louçã 1989). Hopefully, we contribute with insights and advice that are useful for policy makers and entrepreneurs in many technology fields.

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Notes

1. There has been an equal contribution to this paper by Hillman and Suurs.
2. For a more general account on the characteristics of the formative stage of technological systems, see Van de Ven (1993), Rip and Kemp (1998), Unruh (2002) and Jacobsson and Bergek (2004).
3. This definition is based on the one by Carlsson and Stankiewicz (1991). For an alternative definition in this special issue, see the contribution by Bergek, Jacobsson and Sandén (2008).
4. For an argument on the applicability of the innovation systems approach to the issue of energy system innovation, see also Sagar and Holdren (2002).
5. See also the more recent work by Balzat and Pyka (2006) who do a cluster analysis on the innovation system characteristics of OECD countries to classify different systems into groups.
6. They thus differ slightly from the functions used by Bergek, Jacobsson and Sandén (2008).
7. By leaving these factors outside the TIS, we run the risk of missing out dynamics 'on a higher level'. In return, this makes possible a more detailed analysis of the factors included.
8. For a historical perspective on the concept, see Skott (1994).
9. The idea of a virtuous or vicious circle is rather abstract. As we will see, the actual dynamics of a TIS, are often not exactly circular. Even under presence of positive interactions between system functions, we will find that developments

tend to be more chaotic than the ideal type of a recurring circle. Nevertheless the concept of a circle is useful as it provides a reference point to relate our findings to. We follow a rather narrow definition of what is virtuous and what is vicious dynamics; the division merely captures the dynamics of the TIS and does not (directly) relate to the desirability of the TIS or the technology it surrounds. Note that Myrdal's original concept of a vicious or virtuous circle was applied to large social systems. As we are now dealing with a far more specific problem, the development of a TIS, it could very well be that the concept does not apply in the same way. This is the reason why our research results are theoretically relatively 'loose' and mostly oriented towards close empirical observations. On the other hand the concept has been applied earlier with success; cf. Jacobsson and Bergek (2004).

10. This paper springs from two previous studies from the Netherlands and from Sweden, presented in Suurs and Hekkert (2005, 2008), and Sandén and Jonasson (2005), respectively. Both studies were based on empirical material collected from articles in periodicals and newspapers, and reports from governmental agencies, academia and consultancy firms. Literary sources were supplemented by interviews with key persons involved, and the results found were checked through discussions with industry representatives.
11. This has been empirically shown by Negro, Hekkert, and Smits 2007; Negro, Suurs and Hekkert 2008.
12. The targets were 2% for 2005 and 5.75% for 2010, of the petrol and diesel used for transport purposes (EU 2003).
13. It may seem inappropriate to consider the technology dimension an exogenous factor, but this is a matter of delineation. Adhering to the tradition of innovation system studies, we choose to focus on the societal dynamics around technology development.
14. There are also significant activities related to other biofuels. The accounts given here are for the large part based on more detailed event analyses; see Suurs and Hekkert (2005, 2008), and Sandén and Jonasson (2005), for a more elaborate account.
15. Ministry of VROM (Interview 2006). Personal communication with senior policy maker.
16. GAVE (Gasvormige en Vloeibare Energiedragers): Platform for Gaseous and Liquid Fuels; Novem (Nederlandse Onderneming voor Energie en Milieu): Dutch Agency for Energy and the Environment. The agency is mainly responsible for executing government policy on energy, innovation and sustainability.
17. GAVE (Interview 2005); personal communication with Eric van den Heuvel: Programme Manager GAVE.
18. *Ibid*.
19. *Ibid*.
20. Knowledge network, active in development of advanced bioenergy conversion technologies. The network consists of oil company Shell, ECN (Energy research Centre of the Netherlands), and numerous universities, technology institutes and energy companies.
21. TNO is the Dutch Organization for Applied Scientific Research. The network consists of TNO, a number of companies active in chemical engineering and energy distribution.
22. Ministry of Economic Affairs (Interview 2006); personal communication with a Senior Policy Maker.
23. The early adoption experiments are all linked to foreign supply.
24. Foundation for Swedish Ethanol Development, previously SSEU (Interview 2005); personal communication with S. Flodin.
25. *Ibid.*
26. Protima AB (Interview 2005); personal communication with C. Rydén.
27. The interest was partly associated with the Agenda 21 framework after the Rio World Summit in 1992.
28. The Federation of Swedish Farmers (LRF) and Lantmännen (Interview 2005); personal communication with E. Herland.
29. About this time, SSEU was renamed BAFF (BioAlcohol Fuel Foundation).
30. Flexifuel vehicles can run on any mix of petrol and E85, which consists of 85% ethanol and 15% petrol.
31. Protima AB, see note 26.
32. *Ibid.*
33. *Ibid*.
34. The strategy was mainly in support of gasification technology producing other fuels than ethanol.
35. In parallel, pilot plants for gasification technology (i.e. not related to ethanol) – were prepared.
36. Note that the guidance function need not necessarily be fulfilled by policy makers. In fact, entrepreneurs themselves can play an important role, for instance, by collaborating through the formation of advocacy coalitions. However, for the long-term perspective it turns out that government leadership is a requirement.
37. The development of various technologies can only be stimulated through the use of several different policy instruments in parallel. See Sandén and Azar (2005) on the need for technology differentiated support. Of course, there is need for a balanced view, as too much focus on 1G technologies may lead to a dead end. See Hillman and Sandén (in press).

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