Competing innovationsystems and the need for redeployment in sustainability transitions

Thomas Magnusson and Christian Berggren

The self-archived postprint version of this journal article is available at Linköping University Institutional Repository (DiVA):
http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-141195

N.B.: When citing this work, cite the original publication.
Magnusson, T., Berggren, C., (2017), Competing innovationsystems and the need for redeployment in sustainability transitions, Technological forecasting & social change. https://doi.org/10.1016/j.techfore.2017.08.014

Original publication available at:
https://doi.org/10.1016/j.techfore.2017.08.014

Copyright: Elsevier
http://www.elsevier.com/
Competing innovation systems and the need for redeployment in sustainability transitions

Thomas Magnusson (corr. author) and Christian Berggren
Linköping University
Dept. of Management and Engineering
SE-581 83 Linköping, Sweden
thomas.magnusson@liu.se
christian.berggren@liu.se

Abstract

According to sustainability transitions theories, innovation policies should create protective spaces (‘niches’) for promising new technologies. Moreover they should support a cumulative process of market formation and growth. Based on results from comparative case studies of two competing technological innovation systems for heavy transport (biogas and electrification), this paper argues that these recommendations are contradictory when technology alternatives with different degrees of maturity compete for the same niche. Should innovation policies open up the niche for the promising but immature alternative, or should they continue to support the technology that already has attained a niche position? If this contradiction remains unsolved, there is a risk for conflicts that block the progress of both alternatives. The paper suggests that there is a need for differentiated policies to resolve the contraction. In order to facilitate further development of both systems, the paper suggests that niche nurturing for immature systems needs to be combined with redeployment into new market segments for more mature systems.

Keywords

Technological innovation system; strategic niche management; technology competition; system redeployment; market formation; niche accumulation
1. Introduction

The technological innovation system has emerged as an influential concept in academic debates on the design of policies to stimulate environmental innovations and facilitate sustainability transitions (e.g. Binz et al., 2012; Hekkert & Negro, 2009; Markard, Stadelmann, & Truffer, 2009). Several authors in this literature emphasize the need for technology-specific policies based on the argument that environmental innovations suffer from a double externality problem (Olta & Saint Jean, 2009). Smith and colleagues suggest that there is a need for protective spaces, i.e. narrow areas of application or market segments (‘niches’) that can nurture the development and early diffusion of alternative new technologies (Smith et al., 2014; Smith & Raven, 2012). Through a cumulative market formation supported by bridging markets (Andersson & Jacobsson, 2000), the innovation system will then gain power and expand, and the new technology will eventually be able to compete with established technologies on mainstream markets (Suurs & Hekkert, 2009b).

Competition between immature and established technologies has been a prime focus in the literature on technological innovation systems and sustainability transitions. However, recent contributors draw attention to more complex processes of competition involving several sustainability alternatives in the same niche (Alkemade & Suurs, 2012; Bakker, van Lente, & Engels, 2012; Suurs & Hekkert, 2009a; Wirth & Markard, 2011). Such competition presents policy-makers with more difficult challenges than the ‘nurture and bridge’-recommendations emanating from the existing literature.

The transport sector poses a notorious challenge for policies intending to reduce greenhouse gas emissions (Stern, 2007) and a highly relevant area for the analysis of competing technologies. Within land-based transport, emissions from heavy vehicles tend to be a particularly difficult issue because of continuously increasing transport volumes. This paper analyses two competing sustainability technologies within this sector in Sweden, where an intense competition is unfolding between the two alternatives biogas and electrification. The purpose of the paper is to understand the emergence of this competition and its implications, the justifications presented for the technologies, and the policies required to support a positive development of both systems.

The next section elaborates theoretically on niches, technological innovation systems, technology competition and processes of market formation. Thereafter, a method section introduces the cases and the research design, followed by two empirical sections on biogas and electrified heavy vehicles respectively. The subsequent section compares the technological innovation systems and discusses possible policy approaches to deal with the challenge of competition between sustainable technology alternatives. A concluding section summarizes the main findings and implications.

2. Technological innovation systems and the role of niches

2.1 Niches as protective spaces
The concept of niches have obtained a prominent role in theories on sustainability transitions, describing a way for promising new technologies to escape the R&D laboratory. New technologies are often disfavoured by existing selection environments because infrastructures, organizations, practices and regulations are defined according to established technologies. Therefore, new technologies need protection. Niches are important in this respect, shielding the new technology from premature competition, providing a space for the formation of networks to facilitate interactive learning, empowering the emerging innovation system and nurturing radical innovation (Smith & Raven, 2012; Boon & Bakker, 2016).

Synthesising literature on niches and sustainability transitions, Schot and Geels (2008) describe two kinds of niches: technological niches and market niches. Technological niches refer to demonstration projects where technology suppliers meet potential users and other actors, who may influence the shaping of a demand. These niches are instrumental for the articulation of expectations and visions about the new technology. Moreover, they attract attention to and legitimize the technology, facilitate sociotechnical experiments and help building social relationships (Hoogma, 2002; Caniëls & Romijn, 2008). Literature on sustainability transitions present strategic niche management (SNM) as a guidance for policy, emphasising the need to initiate demonstration projects (Harborne, Hendry, & Brown, 2007; Kemp, Schot, & Hoogma, 1998; Schot, Hoogma, & Elzen, 1994). To qualify as technological niches, such policy-supported demonstration projects will have to involve a variety of stakeholders, thus facilitating alignment between the technology and the society (Rip, 1995).

Market niches constitutes a successive step. The concept refers to “niches in which technology design and user demands have been stabilised” (Schot & Geels, 2008:539). Hence, rather than describing a space for experimentation, market niches describe possibilities for new technologies to enter a commercial stage. The concept of a market niche rests on an assumption of markets as being heterogeneous, consisting of different segments that describe different application domains and selection environments (Levinthal, 1998). A new technology stand a better chance if it enters in a segment where the particular selection environment is more benign to the technology. Because these segments tend to be relatively narrow and the sales volume small, it is customary to describe them as niches. Case studies suggest that policy has a central role to stimulate the emergence of market niches for cleaner new transport technologies (Sushandoyo & Magnusson 2014; van der Vooren & Brouillat, 2015). To be successful in this, the policy has to comprise combinations of different instruments such as extended demonstration programs, procurement requirements and subsidies.

2.2 Technological innovation systems

The technological innovation system (TIS) approach presents an elaborated framework on the prerequisites for a successful diffusion of new technologies. A TIS consists of the actors, networks and institutions associated with the technology. These are structural building blocks
of the system (Bergek et al., 2008). On the back of its multi-dimensional character, the TIS approach then suggests a number of processes (often denoted ‘functions’) which are critical for the system to evolve. This includes processes of experimentation into a variety of applications and production methods, knowledge development and diffusion, legitimation, mobilization of resources, direction of search processes and market formation (Hekkert et al., 2007; Hekkert & Negro, 2009; Bergek et al., 2008; Hillman et al., 2011). The functionality of a TIS can be assessed in terms of the relative strengths and weaknesses of these processes, where strengths and weaknesses can be related to factors either within or outside the system (Hellsmark, et al. 2016). A key objective for innovation policy then is to stimulate weak processes/functions and remove obstacles that may hamper them.

Different TIS have reached different stages of maturity. A common way to assess maturity is according to the stage of technology diffusion, which tends to follow an S-curved pattern (Geroski, 2000). Analysing cases of renewable energy technologies, Jacobsson and Bergek (2004) make a distinction between the formative stages and the growth stages of a TIS, arguing that different kinds of policies are required to sustain progress during these two stages. Whereas the formative stages consist of pre-commercial R&D and demonstration, as well as early diffusion on niche markets, the growth stages are characterised by diffusion on larger segments and subsequently on mass markets.

A TIS operates in a multi-dimensional context and its contextual interactions differ in terms of strength and dependency. Bergek et al. (2015) distinguish between four kinds of context dimensions: technological, sectorial, geographical and political. Technological contexts refer to other technological innovation systems with which the focal TIS interacts. These can be divided into complementary and competing TIS (Markard & Hoffmann, 2016; Sandén & Hillman, 2011). Sectorial contexts refer to structures that provide societies with a certain functions, such as energy, transport or food (Malerba, 2002). These structures facilitate production, distribution and use of different services and products. While sectors have similar structural elements as technological innovation systems, sectors incorporate different technologies and a TIS is often embedded in one or several sectors (Bergek et al., 2015). Geographical contexts refer to the place in which the TIS is situated. Analyses of TIS have often had a national delimitation, but system evolution depends on activities and interactions at different geographical levels, ranging from local to global (Coenen, Benneworth, & Truffer, 2012). While some system actors have a geographical jurisdiction, such as a local municipal board or city council, others operate globally, such as an international firm. The political context is about the argumentation for (and against) the technology. The interests of various actors determine their engagement in and relationship with a TIS, and norms, practices and power relations direct possibilities for future developments. The politics of sustainability transitions refer to ideas and understandings about environmental and societal problems that define the space of acceptable solutions (Meadowcroft, 2011).

2.3 Transitions and technology competition
Literature on sustainability transitions tends to embody a normative orientation, describing ways to substitute established technologies in different applications. TIS and SNM present ways to support such substitution processes through technology-specific policies. Two main arguments justify these policies. Firstly, existing selection environments tend to disfavour new technologies and secondly, environmental innovations will make the society more sustainable and therefore they deserve public support (Oltra & Saint Jean, 2009). These arguments warrant policy interventions that may make it possible to attain increasingly larger market shares at the expense of established technologies.

However, the reality may be more complex than one-to-one substitutions of established technologies with new alternatives. Bakker, van Lente, and Engels (2012) found that several alternatives often compete for policy protection, justified by promising expectations in terms of sustainability. The authors conclude that although there could be room for a number of different alternatives in local demonstration projects, a continued development and growth will require some selection. Moreover, Wirth and Markard (2011) have shown that effective support schemes may foster a lock-in to certain technologies. Thus, there is a risk that policy-support will result in a barrier for the development of newer, less mature but more promising alternatives. Farla, Alkemade, and Suurs (2010) argue that in sectors such as energy and transport, which require large infrastructural investments, earlier decisions can result in irreversibility and lock-ins. Therefore, sustainability transitions require higher-level policy approaches, considering several technology alternatives and different development paths.

In particular, studies of sustainable mobility show that alternative fuels and vehicle technologies compete both with the established fossil-fuel based system and with each other, engaging actors and coalitions at various social levels (Alkemade & Suurs, 2012). However, in sustainability transitions literature, the recommendations on how to deal with such competition have remained vague. As long as there is just one ‘focal’ technology that deserves support, literature on TIS and SNM present consistent and complementary recommendations for technology-specific policies. However, in cases involving several technology alternatives at different stages of maturity, these recommendations tend to be conflicting. On the one hand, TIS theories recommend continued support to facilitate cumulative development and growth. On the other hand, SNM recommend that policies should open up niches for immature but promising new alternatives. To find a way to solve this conflict, we turn to the concept of system redeployment.

2.4 System redeployment

Both theories on TIS and on SNM rest on evolutionary economics, a research field that has evolutionary biology as its prime source of inspiration (Smith & Raven, 2012). According to Dosi and Nelson (1994) a key element in such evolutionary theories is the modeling of system evolution as “processes of imperfect (mistaken-ridden) learning and discovery, on the one hand, and some selection mechanism, on the other” (p. 155). According to evolutionary biology, redeployment describes a creative reuse of existing resources for new purposes. In
studies of how the brain’s cognitive functions develop, Anderson (2007) makes an analogy to component reuse in software engineering, arguing that the brain has an ability to reuse components that originally were developed to serve another purpose. Through processes of recombination, incorporated into the functional network of brain regions, these components may support new capacities and fulfill new tasks. Other sub-disciplines within evolutionary biology have found similar processes, including the conservation of systems across species and their subsequent evolution to serve different purposes (Relaix & Buckingham 1999).

Adopting evolutionary perspectives on firm strategy, management literature have used redeployment to describe how firms can migrate from shrinking or unprofitable markets or segments to more promising markets (Anand et al., 2016; Helfat & Peteraf, 2003). The intentional departure from the existing market makes redeployment different from diversification strategies, which generally aims for growth through entry on new markets while retaining the position on existing ones. A recent analysis by Weigelt and Shittu (2016) of firms’ redeployment decisions from fossil fuels to renewables in the U.S energy sector emphasizes the role of uncertainty in these decisions and the impact of regulatory mandates to reduce this uncertainty. Without such mandates, firms used other firms as references for their investments, but with mandates in place those mandates became an important guide for the decisions. Investigating Norwegian oil and gas firms entering the market for off-shore wind power, Mäkitie et al. (2016) present similar results. They conclude that in absence of policy initiatives that undermine the existing business – such as discontinued governmental support for exploration of new oil fields – the oil and gas firms’ commitment to the new business tended to be marginal.

Whereas a firm can be regarded as a strategic actor that is hierarchically controlled and coordinated, technological innovation systems comprise a multitude of actors. Therefore, agency is more distributed in a TIS than in a firm. Still, it is possible to observe redeployment processes at a systems level. Braunerhjelm et al. (2000) present a comparative analysis of emerging polymer and biomedical clusters in Ohio and Sweden, suggesting that an effective transfer of resources from declining industries such as steel, machinery, and automobile was decisive for the structuration and growth of these technology-based sectors. They conclude that to facilitate such a transfer, there was a need for a supporting and coordinating structure including academic institutions, research institutes, public policy agencies, industry associations, and finance.

The cases provided by Braunerhjelm et al. (ibid) describes a resource redeployment process from mature industries to promising new ones. This is analogous with the firm-level cases provided by Weigelt and Shittu (2016) and Mäkitie et al. (2016). However such resource redeployment do not sufficiently describe the process needed to solve the conflicting SNM and TIS recommendations as outlined above. Instead, there is a need for a system redeployment in which a TIS that has benefitted from niche nurturing and reached a certain stage of maturity redepoys from its original market niche, thus leaving room for a more immature TIS to enter the market. Such system redeployment may be generally relevant when the first TIS has passed its initial formative stages (cf. Jacobsson & Bergek, 2004) and
the second TIS is approaching a commercial stage. Because it assumes a departure from the initial niche, systems redeployment differs from a bridging process in which the TIS captures an increasingly larger market share in a cumulative manner.¹ Figure 1 illustrates the difference between system redeployment, bridging and nurturing.

Figure 1. Nurturing, bridging and redeployment for the development and growth of technological innovation systems

In strategic management, the rationale for redeployment is reduced profits on a firm’s existing market, and the necessity to move to new markets or segments (Helfat & Peteraf, 2003). The transfer of resources from declining industries to growth sectors rest on similar motives (Braunerhjelm et al., 2000). However, sustainability transitions involving multiple technological innovation systems convey a different reason for redeployment: the need to support a simultaneous development of several alternative technologies and their non-competitive diffusion into different markets and market segments (cf. Stern, 2007). The overall challenge then is to avoid excessive overlap, lock-in and in-fighting between the sustainability alternatives.

¹ Geels (2005) use ‘niche accumulation’ to describe a similar market formation process in which a technology captures increasingly larger market segments in a cumulative manner. However, we prefer ‘bridging’ to reserve the market niche concept to describe small segments that enable initial market entry.
3. Case selection and research methods

3.1 The heavy vehicle industry

This paper uses the TIS approach to analyse competition between sustainability alternatives at different stages of maturity, and then elaborates on dilemmas resulting from this competition, as well as possible solutions. The studied cases are selected from heavy vehicles, but problems of competition between alternative fossil-free technologies are not limited to this industry and to the transport sector (e.g. Srinivasan et al., 1999). The heavy vehicle industry displays several differences compared to the more frequently studied car sector. One difference concerns scale. Whereas the number of cars produced in the EU and North American region varies between 30 and 35 million per year, the production of heavy trucks and buses in the same region is confined to about 1 million each year (Berggren, Magnusson, & Sushandoyo, 2015). Heavy vehicle manufacturers meet a fragmented market with significant variation in applications and customer requirements, from city buses to refuse trucks, fire-fighting vehicles, and long haulage trucks and coaches. In spite of this variation, powertrains with diesel-fuelled internal combustion engines has been a completely dominant design since the mid-20th century. A key explanation to this dominance is that heavy vehicles are exposed to much more stringent demands on cost, reliability and robustness than cars. This slows down the diffusion of new technologies and make firms hesitant to experiment with alternatives. Consequently, heavy vehicle manufacturers continue to invest in diesel-engine technology with a particular focus on reducing local exhaust emissions (soot and NOx), as required by increasingly stringent environmental regulations (Borghesi & Magnusson, 2016a).

Within heavy vehicles, city buses constitutes an exception. This segment represents a small part of the total heavy vehicle market, with sales in Europe amounting to 7,000 – 8,000 full size city buses per year, but plays a critical role for introducing new technologies that may later spread (Lowe, Aytekin, & Gereffi, 2009). Several factors contribute to this role. Bus operators own their vehicles much longer than truck operators do, often for the vehicle’s entire lifetime of 12-14 years, and this justifies longer pay-off periods. Whereas the routes of distribution trucks tend to be irregular, city buses follow planned routes with regular service and maintenance, which facilitate investments in charging stations for electrification or fuelling infrastructure for alternative fuels. Moreover, city buses operate in public transport systems, where local governments can use public procurement criteria to require higher environmental performance. Altogether, these particularities make it feasible to introduce and refine new technologies in city buses long before entering the much bigger but more conservative truck market.

In the heavy trucks industry, six major manufacturers – Daimler, Volvo, MAN, FIAT/Iveco, DAF and Scania – control more than 90% of EU sales and about 40% of the global production (AEA, 2011). The actor structure in the European bus industry is different. It includes both the major truck manufacturers and a number of small-scale bus manufacturers. These specialised manufacturers purchase their powertrains (engines and gearboxes), and
sometimes complete chassis, from the major truck manufacturers or from independent engine manufacturers. They use this flexibility to serve the varied customer demands and requests for local adaptations, including demands for renewable fuels, or alternative powertrain configurations.

### 3.2 The case of Sweden

The transport sector, including aviation, is one of the major CO₂-emitting sectors in the EU with a long-term trend of increasing emissions. Between 1990 and 2013, its share of the total EU-28 emissions rose from 14.9 % to 22.2 %. Trucks, buses and coaches generate a quarter of these emissions and despite improvements in fuel efficiency, greenhouse gas emissions from heavy vehicles rose by 36% between 1990 and 2010, mainly due to increasing road freight traffic. This problem has engendered an increasing policy interest to identify and implement more sustainable alternatives. This is particularly so in Sweden, where heat and electric power production is overwhelmingly fossil-free, making the transport sector the most significant emitter of greenhouse gases. Reduction of emissions from transport are crucial for achieving the national goals regarding emissions reduction. Based on scenarios presented by a national commission on emissions reduction, the government has espoused a vision to make the national vehicle fleet ‘fossil fuel-independent’ by 2030, implying a “road-transport system whose vehicles mainly are propelled by bio-fuels or electricity” (SOU, 2013: 35-36, authors’ translation). Concerned governmental agencies have realized that substitution of fossil fuels with renewables is not sufficient; an efficient transport system and efficient use of renewable resources is just as important. They have proposed a variety of policy instruments to help fulfill the vision (EM, 2017). This makes Sweden interesting from a policy perspective.

Sweden is also influential from an industry perspective. Two of the six major European manufacturers – Volvo and Scania – have their headquarters, main R&D facilities and major production sites in Sweden. Although these firms sell more than 90% of their output outside their home market, Sweden plays a critical role for R&D and demonstration projects. City buses are a small part of Sweden’s heavy vehicle market: in 2015, 4,400 city buses were in operation compared to 80,000 heavy trucks. Similar to other countries, however, city buses play a disproportionate role for introducing new technologies. Within this segment, an intense competition is unfolding between two alternative technologies, biogas and electrification. This paper will present a comparative analysis of these two innovation systems.

---


4 Swedish Environmental Protection Agency Snabbstatistik, nationella utsläpp av växthushåll år 2015 (Quick statistics, national greenhouse gas emissions year 2015), the transport sector accounted for 33% of Sweden’s domestic emissions in 2015 [http://www.naturvardsverket.se/snabbutslapp](http://www.naturvardsverket.se/snabbutslapp), accessed 2016-06-23
3.3 Data sources and analysis

The study of electrification was initiated by an assignment from the Swedish Energy Agency in 2014 to illustrate the use of the TIS approach outlined by Bergek et al. (2008). The assignment included all electrified heavy vehicles, including buses, distribution trucks and special purpose vehicles, with a particular focus on urban transport. As part of the study, we interviewed key actors in the Swedish innovation system: technology specialists and managers at Volvo and Scania, experts at technical universities and major logistics companies, as well as representatives from bus operators, power utilities and public transportation authorities in Gothenburg, Malmö and Stockholm (the three largest cities in Sweden). We presented the results in a report covering analyses of different energy-related innovation systems (EM, 2014) and discussed the policy implications with officers at the Swedish Energy Agency as well as the Ministry of Energy and the Environment.

Since biogas-fueled buses occupies a significant part of the city bus market in Sweden, we decided to supplement our study of the innovation system for electrified heavy vehicles with a corresponding study of the biogas system. Again, we interviewed representatives for key actors at national and city levels, including energy companies, biogas producers and distributors, and representatives for the national association of bus operators (see Appendix A for a compilation of the interviews). We also attended several workshops and seminars, where proposed policies were discussed and where stakeholder representatives for biogas and electrified heavy vehicles discussed and analyzed prospects for development and growth of their respective innovation systems (see Appendix B for a compilation of the attended workshops/seminars). To expand our insights in industry dynamics, the emergence of new entrants, and the launch of new products from established firms we visited the industry fair IAA Nutzfahrzeuge in Hanover, in October 2014. Here we could meet representatives from several specialized bus manufacturers and key suppliers, as well as the major heavy vehicle manufacturers. In addition to this, the study includes secondary data from policy documents and relevant academic papers.

The case analysis relied on an abductive research approach (Alvesson & Sköldberg, 2009), systematically combining theory with empirical observations in a stepwise validation process. In this context, the interaction with stakeholder representatives at workshops and seminars provided opportunities to reflect upon and dispute our interpretations and propositions. The analysis presented below starts with the individual innovation systems, describing the technologies and their diffusion, as well as the structural elements (Bergek et al., 2008). Since actors and networks are closely related, these elements are compiled in the presentation. The subsections on institutions primarily focus on the institutional support for the systems. The sections on the individual innovation systems conclude in discussions on the systems’ functional strengths and weaknesses (cf. Hellsmark et al., 2016). After the individual TIS analyses, a comparative analysis follows. The comparison starts with the stage of maturity of the two systems, using technology diffusion as an indicator. Then we compare
the two systems in terms their sectorial, geographical, political and technological contexts (cf. Bergek et al., 2015). The analysis emanates in a discussion on policy challenges.

4. The biogas innovation system in Sweden
4.1 The technology and its diffusion

Biogas is a methane-rich compound produced through anaerobic digestion of organic substrates such as energy crops, sewage sludge and organic waste from households, farms and the food industry. Plants designed for co-digestion can use combinations of substrates. It is possible to use biogas for electric power and/or heat generation, in industrial processes, or as a vehicle fuel. Use as vehicle fuel necessitates an added process step to raise the methane-concentration and then compress the gas to CBG (compressed biogas). Then the gas can feed combustion engines designed to burn compressed natural gas (CNG). Replacing diesel-fuel in heavy vehicles with biogas has several positive environmental effects, including improved air quality and reduced greenhouse gas emissions. The reduction of greenhouse gas emissions is an effect both of the substitution of fossil fuels with renewables and the controlled digestion of organic waste and manure which otherwise could generate uncontrolled releases of methane into the atmosphere. Moreover, biogas production may help to solve local waste management problems and farmers can use rest products from the production as soil fertilizers. This may lead to reduced eutrophication and improved utilization of crop nutrients (Lantz et al., 2007).

Most biogas producing countries primarily use the gas as a renewable energy source for electric power and/or heat generation (Raboni & Urbini, 2014). However, the biogas produced in Sweden is dominantly upgraded and used as vehicle fuel. The proportion of upgraded biogas has increased steadily since the late 1990s and reached 57% in 2015 (EM, 2015), which made biogas a leading alternative to diesel in heavy urban traffic in Sweden.
Figure 2 shows the number of gas-fuelled heavy vehicles in Sweden 1995-2015, based on vehicle registration statistics. The difference between vehicle categories is striking. In 2015, about 1% of the heavy trucks used CNG/CBG,\(^5\) compared to 15% of all registered heavy buses.\(^6\) Of city buses in public transport, more than 30% used CNG/CBG.\(^7\) As the figure shows, there has been a particularly robust increase of gas-fuelled buses since 2009.

Biogas production plants in Sweden are primarily located in the densely populated southern parts of the country with 50% of the production concentrated to the regions surrounding the three largest cities Stockholm, Gothenburg and Malmö. Biogas is more difficult to distribute than liquid fuels. In this respect, Gothenburg and Malmö has benefitted from the natural gas grid that runs along the Swedish west coast. Injection of biogas into the grid simplifies distribution and the availability of natural gas makes it relatively easy to blend in a higher percentage of natural gas when demand surpasses the supply of biogas. The natural gas grid does not cover other parts of the country and therefore, cities in the central and eastern parts of Sweden have developed more expensive solutions to enable distribution. The city of Stockholm, for example, has used trucks with pressure bottle containers to transport biogas from neighboring regions and import of liquefied natural gas to compensate for shortages in biogas supply (Lönnqvist, Sanches-Pereira, & Sandberg, 2015).

---

\(^5\) A significant part of these are refuse trucks, which operate in urban areas and are subject to public purchasing from municipalities.

\(^6\) The share of CNG/CBG-fuelled passenger cars in Sweden corresponds to the share of CNG/CBG-fuelled heavy trucks

\(^7\) E-mail conversation with representative for the Swedish Bus and Coach Federation, 2016-03-03
4.2 Actors and networks

Based on a retrospective study of the development of biogas production and use in one of the pioneering Swedish cities, Fallde and Eklund (2015) show how networks of local actors have been critical for the formation of biogas as a technological innovation system. These networks include a variety of public and private organizations: energy companies, farmers, waste and recycling companies, sewage plant operators, municipalities and local or regional transport authorities. Due to the variety of actors involved, biogas is a more complex system than other bioenergy systems (Lantz et al., 2007). However, the close interaction between two specific actors – biogas producers and public transport authorities – have been particularly important for the early development of the Swedish biogas system (Fallde & Eklund, 2015).

On the national level, the system has enjoyed backing from university research and multi-party research centers, for example the Biogas Research Center in Linköping, which is co-funded by the Swedish Energy Agency. Advocacy coalitions operate in different regions and on the national level to inform about biogas, and to promote increased production and use. These coalitions also provide platforms for interaction between system actors and they coordinate activities to further develop biogas production and distribution.

Local actors such as municipal boards, and municipally owned waste management, sewage treatment and energy companies remain critical for the innovation system. However, large private companies have also entered. The international energy corporation E.ON and the gas companies AGA (part of the Linde Group) and Air Liquide (though its subsidiary Fordonsgas) take active part in the development and operation of biogas distribution systems. Both in Sweden and internationally, the German heavy vehicle manufacturer MAN is the leading supplier of CNG/CBG-fuelled city buses. In 2012, Scania introduced a new generation of gas engines for both trucks and buses, compliant with the Euro VI emission requirements. Volvo focuses its efforts in this field on truck applications, having developed a dual-fuel engine that runs on a combination of diesel/biodiesel and liquefied biogas/natural gas.

4.3 Institutions

The 1990s witnessed an increasing public pressure to improve urban air quality in Sweden and other OECD countries, resulting in significant demands to reduce particulate and nitric oxide emissions from diesel engines. This motivated several local initiatives, such as low emission zones in many cities and implementation of alternative fuels, e.g. ethanol, CNG and biogas (Hillman & Sandén, 2008). During the last decade, the focus has moved towards climate change and greenhouse gas emissions. This has resulted in a broad consensus in Sweden concerning the need to replace fossil fuels with renewable alternatives. Being renewable and locally produced, biogas has enjoyed support both among national and local policy-makers.
The Swedish biogas system is influenced by EU directives on biofuels, agriculture and waste management, but also by tax and competition directives. Moreover, the system has to comply with industrial standards on fuel quality. Due to the public discourse on climate change, several national policy instruments in Sweden have supported biogas, including national waste management directives and fuel tax exemptions, investment grants for production and upgrading facilities, as well as various local incentives and initiatives (Larsson, Grönkvist, & Alvfors, 2016). The increasing use of biogas in city buses is an effect of regional public transport authorities’ procurement policies, which stipulate the use of biogas.

In 2015, the national advocacy coalition Energigas Sverige (2015) published a proposed national biogas strategy, arguing that the multiple societal and environmental benefits of biogas justify continued support to compensate for its higher production costs. A controversial issue here is the Swedish tax exemption for biogas as a transport fuel. This exemption is critically important to make biogas competitive with diesel, where taxes constitute more than 60% of the price. However, the Swedish tax exemption has been questioned by the EU commission, and in 2015, the commission announced that the exemption would only be allowed until 2020. In contrast to the transport sector, the EU emissions trading scheme defines heat and power production as a ‘traded sector’. Fossil fuels used here only pay the almost negligible costs of emission permits, which means that fossil fuels easily outcompete biogas as an energy source in this sector. This difference in tax regimes is a major reason for the focus on using biogas as transport fuel in Sweden.

4.4 Functional strengths and weaknesses

Compared to the leading European biogas producing country, Germany, the Swedish biogas production has been scaled-up in a more controlled manner, using substrates from wastes rather than from energy crops. Therefore, Swedish biogas production has not suffered from the legitimacy problems, which the German energy-crop based biogas production has experienced (Markard, Wirth, & Truffer, 2016). However, to establish production resources, there has been a need for investment support (Larsson et al., 2016). Moreover, subsidies has been required to make the use of biogas economically feasible and the innovation system depends heavily on one particular market niche – public transport city buses. Since public transport authorities in most cases settle contracts on bus operations for periods of 8-10 years, the use of biogas in city buses ensures a stable demand, and this has justified investments in production facilities, fuel distribution systems and filling stations, as well as continued knowledge development. The demand has increased steadily for several years, but it is likely to level out or even decline in the future, and several of our interview respondents lamented the difficulty of making any business of biogas, especially outside the city bus niche.

---


9 According to a representative for the energy company Eon, biogas is currently about 2.5 times more expensive than natural gas (interview 2015-12-01).

10 Public transport authority representative at workshop in Linköping 2016-02-05
Data on CO₂-emissions and energy efficiency from Swedish public transport show that the increased use of biofuels (including biogas, ethanol and biodiesel) has resulted in a significant decrease of CO₂-emissions. However, at the same time the energy efficiency has not improved. An important reason for this is that the gas-fueled buses are less efficient than diesel-fueled buses, especially in urban traffic. Recently, representatives for public transport authorities have started to present electrified city buses as a promising strategy to improve energy efficiency (Xylia & Silveira, 2017). However, actors in the biogas TIS perceive the prospect of electrified city buses as a threat, which strikes at one of the main weaknesses of the system – the dependency on the city bus market niche.11 Hence, they advocate a maintained or even strengthened support. A recent example is the national biogas strategy proposed by Energigas Sverige, which argues that any benefits that electrified buses may gain from new political interventions, should apply to gas-fuelled buses as well: “The government has proposed a particular subsidy scheme to increase the use of electric buses. This subsidy scheme ought to include gas-fuelled buses, since they also contribute to a better climate and cleaner air” (Energigas Sverige, 2015:13, authors’ translation).

Olsson and Fallde (2015) use the concept ‘technological style’ to describe the preference in Swedish policy to support local production and use of biogas as a vehicle fuel in urban areas, close to the production sites. According to their analysis, the full potential of biogas will not be realised with this single-minded search direction, and they call for a greater variety. Advocacy coalitions such as Energigas Sverige (2015) recognize this, both arguing that the existing niche should enjoy prolonged protection, and suggesting new applications to make a massive expansion possible, from the current 1.8TWh in 2014, to 15TWh by 2030.

Encouraged by the Swedish government’s vision to make the national vehicle fleet ‘fossil fuel-independent’ by 2030, transport applications should still be the main focus, but these suggestions also include using biogas to replace fossil fuels in energy intensive industrial processes such as steel production, as a fuel for ships and ferries, or for power generation to balance the electricity system. The latter application could facilitate an increased implementation of intermittent energy sources such as wind and photovoltaics. However, as noted above, such an expansion would require major changes in the tax regime to compensate for the cost disadvantage of biogas outside the transport sector compared to fossil fuels.

The national commission on emissions reduction proposed several measures, including a dramatically increased use of biofuels for long-haulage transports (SOU, 2013). However, the commission did not address a major problem for such a shift in the case of biogas: the low energy density of compressed gas in comparison to liquid fuels, which requires vehicles to be equipped with bulky pressure tanks. Such tanks are a lesser concern for city buses, which can place them on the roof, but is a significant problem for long-haulage trucks and coaches. Biogas liquefaction may overcome this hurdle but such a process also implies energy losses, and added costs. So far, production of liquefied biogas (LBG) has only been tested in small-scale operations and the knowledge and methods required for more cost-efficient production are still under development. In 2014, one pilot plant for LBG production was in operation in

11 This was an outcome of a SWOT-analysis, conducted by representatives for actors in the biogas TIS at a workshop 2015-04-22.
Sweden and about 2% of the national biogas production was liquefied and used as a vehicle fuel (EM, 2015).

5 The Swedish heavy vehicle electrification system

5.1 The technology and its diffusion

Electric propulsion is an alternative vehicle technology, which has attracted a strong international interest, mainly in the car sector (Dijk, Orsato, & Kemp, 2013). However, electrification is becoming an increasingly important alternative also for heavy vehicles, in particular those vehicles that operate in urban traffic. Representatives for Swedish public transport authorities place electricity as the most promising alternative fuel and propulsion technology in the near future, referring to potential for improved energy efficiency and zero urban emissions, as well as the silent and vibration-free features of electrified city buses (Xylia & Silveira, 2017). Conventional diesel engines may operate at 40 – 45% energy efficiency on long-haulage routes, but are much less adapted to urban stop-and-go traffic, where the energy efficiency decreases significantly. Here, electrical drive is superior with an energy conversion efficiency close to 80% (Andersson, 2014).

There are different steps of vehicle electrification, starting with stand-alone hybrids. These vehicles are completely compatible with the existing infrastructure and can reduce fuel consumption and greenhouse gas emissions with up to 30-40% in urban traffic. Plug-in hybrids imply another steep change in fuel efficiency and emissions reduction, but in addition to more powerful batteries and motors, they require investments in charging infrastructure. The fully electric alternative is technologically simpler, since there is no need to integrate two different propulsion units (diesel engine and electric motor). However, fully electric vehicles require significant outlays for fast-charging; or alternatively, higher purchasing costs for vehicles with heavy battery packages, plus investments in night-time depot charging supported by high-power grids. For trucks this is not an alternatives since large batteries reduce valuable payload. Thus, according to Swedish manufacturers, the fast-charging/small batteries option is the only alternative for heavy trucks.

In Europe, the first step of heavy vehicle electrification made a decisive move from demonstration to niche market acceptance after an extensive testing and procurement program operated by Transport for London in 2009-10. The Swedish market was slower to introduce stand-alone hybrids, which entered at a time when public transport in major Swedish cities had just started to replace diesel with biogas-fuelled buses (see Figure 2, above). Nevertheless, for the next electrification steps, Sweden is an important market for test and validation, and several cities have initiated projects with these forms of advanced electrification. Umeå in northern Sweden started tests and demonstrations of fast-charged

---

12 For discussions on different hybrid and electric drive configurations and technology strategies for heavy vehicles, see Sushandoyo & Magnusson (2012), Berggren, Magnusson, & Sushandoyo (2015) and Borghei & Magnusson (2016b).
fully electric buses already in 2011. In 2014, the municipality announced a significant upscaling, with purchase of additional buses. In 2015, Stockholm initiated tests of plug-in hybrids in regular traffic and Gothenburg introduced ‘ElectriCity’, a new electrified bus line with a combination of fast-charged plug-in hybrids and fully electric buses. Apart from these cities, several medium-sized Swedish towns have announced small-scale tests of electric buses (Aldenius et al., 2016) and more projects are in the pipeline. As a whole, however, the number of electrified heavy vehicles in operation in Sweden remains limited. Figure 3 shows the number of electrified heavy trucks and buses above 3.5 tons in 2006-15 according to official registration statistics.

![Figure 3. Registered electrified heavy trucks and buses above 3.5 tons in Sweden 2006-2015 (source: The Swedish Transport Agency).](image)

**5.2 Actors and networks**

The heavy vehicle manufacturers are key actors in the Swedish innovation system for electrified heavy vehicles. Since the early 1990s, they have developed various electrification technologies and tested them in different applications, resulting in a significant increase in technical knowledge. A part of this research has taken place within Swedish Electromobility Centre, a public-private partnership involving technical universities and automotive manufacturers, co-funded by the Swedish Energy Agency. As the only major European bus and truck manufacturer, Volvo participated with a recently developed hybrid bus in Transport for London’s comprehensive testing and procurement program. The evaluations showed that these hybrid buses, in addition to significant fuel savings, had a higher availability than conventional diesel buses. This had a positive impact on bus operators’ perceptions about the new technology and after the London trials; Volvo received a string of commercial orders in

---

13 The official statistics does not separate hybrids and plug-in hybrids, but according to information from Volvo Buses, in total 15 plug-in hybrid buses were in operation in Sweden in early 2016.
the UK (Sushandoyo & Magnusson, 2014). In the 2010-16 period, the company sold more than 2500 hybrid buses in about twenty countries, but only about 6% of them in Sweden. In 2014, Scania, the other major Swedish heavy vehicle manufacturer, launched a similar hybrid powertrain in a bus application, and announced start of commercial sales with the first order going to Norway.

In the truck segment, Volvo introduced a hybrid vehicle and delivered approximately 200 units before putting production on hold in 2013. According to a company representative, customers appreciated the technology, but it was impossible to identify any convincing business case. Nevertheless, Scania introduced its own hybrid truck in late 2015. According to their head of hybrid systems development, this vehicle is certified as a low noise truck according to the Piek-Keur Quiet Truck standard which means that it can enjoy extended operation in densely populated European cities, where night-time use of conventional, noisy trucks is prohibited. However, this opportunity does not exist in Sweden where regulation prohibits all night-time use of heavy trucks in inner city environments.

Further electrification steps involving new charging infrastructures require involvement of additional actors such as city planning authorities and energy companies. Outside the transport sector, Sweden has a long tradition of developing electric equipment in collaboration between the leading national equipment producer ASEA (since 1988 a part of the multinational firm ABB) and the major public energy company Vattenfall (Fridlund, 1999). In 2014, Volvo and ABB closed a deal on collaborative development of electrified buses and charging systems, and Vattenfall decided to enter as an active partner in the field tests of electrified city buses in Stockholm.

The development of new systems requires extensive network formation and user involvement. ElectriCity in Gothenburg illustrates this, being the most ambitious project in Sweden’s heavy vehicle electrification system so far. To build broad competence in systems design and operations, as well as service development and costs analyses, the project involves manufacturers, operators, public transport authorities, electric utilities, urban planning departments, as well as project and engineering consultants. Other electric bus demonstration projects also involve actors on the user side. The Stockholm demonstration is part of the ZeEUS project, which the European Commission cofounds, and it aims to gather experience from electric bus demonstrations in ten different EU-cities. This may have an important long-term impact, but in the short-term the effect on actor networks and system formation in Sweden is limited.

---

14 Interview 2014-03-05
15 Interview 2014-03-05
16 Interview 2016-04-28
5.3 Institutions

As noted above (section 4.3), a broad consensus has emerged in Sweden on the need for replacing fossil fuels in the transport sector. As one of the means to reach this vision, the national commission on emissions reduction suggested very ambitious targets for electrification of urban buses and distribution trucks: by 2030, 83% of the traffic work of these vehicles should be based on electricity (SOU, 2013). The commission gave three main reasons for focusing electrification strategies on city traffic. Firstly, the energy efficiency of electric propulsion in urban traffic is superior to other alternatives. Secondly, silent and emission-free drive is particularly attractive in cities and in the case of buses, electric propulsion enables routes in densely populated areas and strengthens the attractiveness of public transport. Thirdly, the transition to electric propulsion means that the biofuels, which are currently used in city buses, can be used more efficiently in other types of vehicles. In particular, the commission projected a radically increased use of biofuels in long-haulage transports.

An additional argument for electrification refers to the potential for industrial development: "Sweden has the possibility to play a decisive role for the continued development through its vehicle industry. This is particularly true in the case of heavy vehicles, where the Swedish manufacturers are large in an international perspective" (SOU, 2013:39, authors’ translation). Hence, Swedish government agencies have allocated significant funds to research, development and demonstration of electrified vehicles. A report from 2014 estimated the annual public spending to about 40 million euros, half from national agencies and half from regional authorities and municipalities. However as late as 2014, the main part of the national public spending focused on cars, few projects had addressed city buses, and no regional/local projects supported tests and demonstrations of electrified trucks (RS, 2014).

In 2015 though, the new Swedish government introduced two new national support packages. One package allocated 350 MSEK in subsidies for the purchase of electrified buses (plug-in and full electric) with the following argument (authors’ translation): “Electric buses result in reduced greenhouse gas emissions and lesser noise, and make biofuels available for other heavy vehicles, which are more difficult to electrify. Swedish manufacturers will soon start series production of electric buses and fast-charging stations. Part of their activity is also to participate international industry coalitions for the standardization of the vehicle-charging interface. The Swedish government estimates that a specific subsidy to electric buses can contribute to an increased demand and thereby additional employment opportunities”. The second government package, ‘Stadsmiljöavtalet’ (Urban environmental contracts) allocates 2000 MSEK to the planning and implementation of low-emission public transport systems (vehicles excluded), combined with urban planning and expansion. In late 2015, the first round of the program distributed 250 MSEK to projects such as new tramways, bus rapid

17 1SEK = 0.11€ (June 2016)
transport systems and charging infrastructure for electric buses. Following the announcement, Malmö, the third largest city in Sweden, started to explore the possibilities to electrify several frequently operated city bus lines, and in 2016 signed an agreement with the regional public transport authority to gradually introduce electrified buses on all city bus lines (Maasing, 2016).

5.4 Functional strengths and weaknesses

As noted in section 3.1, city buses constitute a strategic entry market for innovative transport technologies. This is particularly true for electrification. Urban conditions maximizes the advantages of the low noise, zero emissions and high internal efficiency of electric propulsion. The fixed routes and frequent operation ensures a high utilization of charging infrastructure, which justifies the necessary investments. For the heavy vehicle industry as a whole, a successful demonstration and diffusion in the city bus segment could also enable diffusion of the electrification technology to related larger segments, such as trucks for urban goods distribution. In terms of technology, the Swedish heavy vehicle manufacturers promote technologies with fast-charging and compact battery packs. Compared to buses with large batteries and over-night charging, this implies a more complex system and investments in distributed charging, but is more promising in terms of vehicle costs and potential for diffusion to truck applications.

For manufacturers, references on the home ground are important to create legitimacy for their technology on international markets. As shown in section 4.1, however, another alternative – biogas – occupies a significant part of this important entry market in Sweden. Long contracts between public transport authorities and private operators make it difficult to introduce another technology before the contracts expire. Swedish transport authorities normally have no financial resources to purchase vehicles and install new charging infrastructure, which makes them unable to experiment and develop knowledge directly from test operations and real-time dialogue with the manufacturers. On the international market, conventional diesel buses are still the major competitor with a considerably lower purchasing price than electrified buses. The limitations of the city bus market and the absence of a growing electric truck business mean that production volumes remain low, which exacerbates the cost problem. To overcome this hurdle, government subsidies have an important role to play. British experiences, for example in Nottingham, indicate that electric buses can attract a significant citizen interest, especially if they are combined with creative re-routing of bus lines, convenient positioning of bus stops, and new forms of city planning. These experiences suggest that electrification has a potential to build a strong local legitimacy. However, the demonstrations projects in Sweden so far have been too limited to generate such a legitimacy. Financial support through governmental programs constitute a significant commitment at the national level, which strengthen the direction of search for heavy vehicle

---

19 Interview with policy expert at K2 - Sweden's national centre for research and education on public transport, 2016-06-19

20 Manager of public transport in Nottingham city at seminar in Gothenburg 2014-05-21
electrification initiatives. A further development depends on initiatives at regional or local levels.

6 System comparison and policy challenges

6.1 System maturity

Using the number of registered vehicles as an indicator, the two systems studied – biogas and electrification – have reached different stages of maturity. Gas-fuelled buses with biogas as a preferred alternative in southern Sweden have achieved a significant share of the urban market, on the back of a variety of public and private initiatives. However, in the much larger truck market, the diffusion of gas-fuelled vehicles is almost negligible, at around 1 percent. Thus, the system is still confined to a particular niche – city buses. To advance further, biogas has to find ways to substitute fossil fuels on larger market segments, within or outside the transport sector. To achieve this, the biogas TIS has to develop out of its local context, engage with new actors and overcome its current technological style with an exclusive attention on urban transport applications.

Electrified heavy vehicles are currently also confined to the urban segment, but at a lower level of maturity than biogas-vehicles. Stand-alone hybrid-electric buses are sold on a commercial basis, but mainly outside Sweden. More advanced electrification steps (full electric and plug-in hybrid) have only been implemented as demonstrations in single bus lines in Sweden, although the number is increasing. Electrified trucks represent a potential volume market and stand-alone hybrid trucks have been demonstrated, but take-off on these larger segments appear distant. To advance the system further, the scale of implementation needs to increase, involving larger vehicle fleets and larger parts of the urban transport systems.

6.2 Contextual analysis

In terms of the sectorial context, both biogas and electrification belong to the transport and energy sectors, but they are linked to different parts of the energy sector. Additional diffusion of electrified heavy vehicles depends on investments in electric energy (charging infrastructure and grid design), as well as city planning and housing development. Biogas vehicles are related to fuel production and distribution, which is another sub-field of the energy sector, as well as waste management and agriculture. The gas producers use sewage sludge and organic wastes from households and food industries as substrates for their production. Farmers receive waste products from this production, which they use as soil fertilizers. However, farmers may also act as suppliers of substrates - energy crops or organic waste - to the gas producers. Hence, the sectorial context of the biogas system is disparate and multi-faceted, which can explain why a multitude of system actors have felt a need to engage in different kinds advocacy coalitions.
Turning to the geographical context, there is a significant difference in the scope of the two systems. Although international firms have entered as distributors of biogas, the biogas TIS still has a strong local orientation. Municipalities, local energy companies and regional public transport authorities have been crucial for system formation and continue to be core actors. At the same time, the system depends on national and international policies, including EU decisions and directives, as well as decisions by international vehicle manufacturers to provide gas-fuelled vehicles to the Swedish market. By comparison, the electrification system has had more of an international orientation from the start. The Swedish heavy vehicle manufacturers enjoy a strong position on the international market, they are influential in the setting of industry standards, and they have a strong influence on national industry and innovation policies. However, even when the Swedish government launch subsidy schemes to stimulate the market for electrified city buses, local and regional policies still determine public transport operations, thus having a key role in the market formation process.

For both systems, the geographical context is closely related to the political context. On the national level, biogas and electrification appear as complementary solutions in the vision of a fossil-independent transport system. However, the argumentation in favour of the two solutions differ. Proponents of biogas stress the environmental benefits of this alternative, portraying biogas as a renewable, locally produced fuel, a way to recycle organic waste, and a source of bio-fertilisers for ecological agriculture. The use of biogas in public transport buses serves to visualise this recycling for city inhabitants, although travellers hardly experience any difference from a modern diesel bus. Proponents of the electrified bus alternative, on the other hand, emphasize its superior energy efficiency, low-vibration and low-noise ride, and zero exhaust emissions. An added argument is that Swedish industry can have a leading international role in the electrification of heavy vehicles, if it is supported by its domestic market.

For biogas, natural gas has been a complementary system. The development of the biogas TIS has benefitted from the availability of CNG-vehicles, and from the natural gas distribution system. In a corresponding way, the electrification system benefits from the electric distribution system. Both biogas and electrification compete with the established technology, vehicles fuelled by fossil diesel. They also compete with liquid biofuels such as bio-diesel, which have competitive advantages over both biogas and electrification because they are compatible with established fuel distribution infrastructure and vehicle technologies. Biogas and electrification depend on the same product application: city buses, which is a very small segment of the heavy vehicle market. For electrified heavy vehicles, city buses are crucial for market entry. For biogas, the same niche constitutes its most valuable protective space, constructed and maintained by local networks and a system of supportive technology-specific policies. Consequently, there is an increasing competition between these two technological innovation systems. Policy makers at different levels are involved, from local municipal boards and regional public transport authorities, to the national government and the EU commission. Proponents of each technology plead for political interventions to gain relative advantages, pointing at the particular merits of their technology. Whereas actors in the electrification TIS seek political support to remove obstacles for market entry and
facilitate investments in buses and charging infrastructure, actors promoting biogas insist on continued support for production and tax-breaks for its current use, as well as incentives for broader diffusion. Table 1 summarises the contextual comparison.

Table 1: Contextual comparison (shared contextual elements in italics)

<table>
<thead>
<tr>
<th>Contextual dimension</th>
<th>Biogas system</th>
<th>Electrification system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sectorial</strong></td>
<td><em>Transport, Energy (fuel production and distribution), Waste management, Agriculture</em></td>
<td><em>Transport, Energy (electric power supply), Urban planning</em></td>
</tr>
</tbody>
</table>
| **Geographical**     | Local orientation
Dependent on national and international policies.
*Local/regional policies determine important market niche.* | International orientation
Strongly related to national industry and innovation policies.
*Local/regional policies determine important market niche.* |
| **Political (main arguments)** | Local production and use.
Circular flows
Solution to several environmental problems | Superior energy efficiency
Clean and silent
Swedish firms have a leading international role |
| **Technological**    | **Complementary TIS**
Natural gas | Electric power |
| **Competing TIS**    | *Diesel, Liquid biofuels, Electrification* | *Diesel, Liquid biofuels, Biogas* |

6.3 Policy challenges

The competition between biogas-fuelled and electrified city buses leads to fragmentation of an already small niche, exacerbates difficulties to reduce costs, and consumes local resources and energies in zero-sum contests. After a long period of negligible support beyond R&D for heavy vehicle electrification, the Swedish government announced national support both for the purchase of electrified buses and for investments in charging infrastructure (see section 5.3). To deflect opposition from biogas system proponents, the government argued that electrification would make the biofuels that city buses currently use available for other heavy...
vehicles. Instead of competing with each other, the two innovation systems would thus attain complementary roles in the overall ambition to make the Swedish vehicle fleet independent of fossil fuels.

However, the problem for the biogas system is not availability, but its close links to local production and consumption, as well as its subsidized use in one specific market niche. The local orientation has reduced the need for extensive investments in the fuel distribution infrastructure. However, to enable efficient use for longer transports, biogas needs more advanced distribution and production systems, which involves liquefaction to avoid bulky gas containers. This means significant investments in production and distribution, as well as in vehicles. Biogas can also be used for local power and heat production in agricultural and industrial sectors, but such a use is difficult to justify economically, given the record-low electricity prices in Sweden, and lack of incentives. A way of circumventing the obstacle related to power production and industrial use would be to introduce a national mandate stipulating a certain percentage of biogas in the natural gas system, similar to the scheme in place in the Swedish transport sector, where all petrol contains 10% ethanol. This could help improving the environmental performance of the gas used in power generation and industrial processes. However, to realise this there is a need to convince actors in these sectors that it is legitimate that they absorb the higher costs of biogas.

A redeployment of biogas out of the ‘city cage’ implies a creative reuse of existing system resources and knowledge in new contexts. To be able to reach new markets or market segments, the biogas system also has to mobilize new resources, develop knowledge about new applications and diffuse knowledge about biogas to new actors. This is difficult to accomplish without the support from a menu of policy instruments. At the same time, the heavy vehicle electrification system also needs targeted policies, administrative as well as economic. This is required both to nurture growth in the city bus niche, and to bridge the TIS into the distribution truck market, which is necessary both to create economies of scale and to make a significant impact in terms of CO₂-emission reductions. The policymaking has to engage several different elements and actor groups: besides national subsidies for investments in charging infrastructure and vehicles, regional traffic authorities could increase their demands on energy efficiency and reduced emissions in their procurement, and cities could gradually introduce ultra-low or zero emission zones.²¹ Table 2 presents examples of implemented and proposed policy instruments on different geographical levels in Sweden with the ambition to support biogas and electrified heavy vehicles.

---

²¹ Such zones are planned in several major European cities.
Table 2 Examples of policy instruments for simultaneous support of Electrification and Biogas (examples from the Swedish context in March 2017)

<table>
<thead>
<tr>
<th>Geographical level and policy actor</th>
<th>Biogas system</th>
<th>Electrification system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>National</strong>&lt;br&gt;Government agencies on energy, transport and R&amp;D</td>
<td>Mandate of a certain percentage of biogas in natural gas (proposed)&lt;br&gt;Support for investments in regional biogas liquefaction facilities (partly in place)&lt;br&gt;Short-term subsidies for purchase of LBG-vehicles (proposed)&lt;br&gt;Support for industrial upscaling and efficiency improvements in liquefaction processes (proposed)</td>
<td>Temporary subsidies for purchase of electrified city buses (in place) and distribution trucks (proposed)&lt;br&gt;Support for investments in urban charging infrastructure for city buses (in place) and for extending this to distribution trucks (proposed)&lt;br&gt;Support for advanced modelling of charging infrastructures (partly in place)</td>
</tr>
<tr>
<td><strong>Regional/local</strong>&lt;br&gt;Public transport authorities and County administrative boards</td>
<td>Planning of fuel distribution infrastructure and investments in LBG-vehicles for inter-city traffic (proposed)&lt;br&gt;Network support &amp; training for farmers in agricultural biogas production and use in local power production (proposed)</td>
<td>More stringent purchasing requirements regarding energy efficiency and noise in city buses (partly in place)</td>
</tr>
<tr>
<td><strong>Local</strong>&lt;br&gt;Municipalities</td>
<td>Divestment/privatization of biogas facilities (initiated)</td>
<td>Development of integrated city planning, including charging infrastructure for electrified heavy vehicles (proposed)&lt;br&gt;Ultra-low or zero emission zones and noise regulations in cities (proposed)</td>
</tr>
</tbody>
</table>

The table illustrates the importance of analysing the progress and potential of different systems from the perspective of overall sustainability transition. In particular, it highlights the necessity of coordinated approaches to support a further development and growth of two competing systems, which have reached different stages of maturity: niche nurturing in the
city bus segment and bridging into the related distribution truck segment for the immature electrified heavy vehicle system; gradual dismantling of the existing niche protection in city buses and support for system redeployment into new contexts for the more mature biogas system.

7 Conclusion

Literature on technological innovation systems (Bergek et al., 2008; Suurs & Hekkert, 2009b) suggests that political interventions are justified to assist diffusion from niches to larger markets. This type of analysis tends to concentrate on one ‘focal’ TIS; the single case study is still the dominant research design in this field. However, our study of two competing sustainability alternatives points at the risk of deriving technology-specific policies from an analysis of one TIS without consideration of other emerging systems with different needs for support. The analysis suggests that sustained technology-specific support for the niche position and cumulative market formation of one increasingly mature TIS may hamper the development of other; less mature but promising systems (cf. Wirth & Markard, 2011). This situation leaves policy actors at different levels with a difficult dilemma. Should they continue to protect the first system with a position and vocal proponents in the most policy-relevant niche or should they open up this niche for the newcomer with a potential to have a broader appeal in related segments? And if they opt for the second alternative, what is appropriate to do with the established niche technology? If this dilemma remains unresolved, there is a risk for conflicts and zero-sum games that block the progress of both technologies.

This paper has introduced system redeployment to describe a policy-supported market formation process that may overcome this dilemma. Rather than encouraging a cumulative process from niches to larger market segments, systems redeployment involves a departure from the initial niche. This may be justified for two particular reasons. The first relates to the dynamic nature of technology evolution. New technologies need to start by entering protected niches to allow for experimentation, adaptation, and learning (Hoogma, 2002; Kemp, Schot, & Hoogma, 1998), but protective policies should be transitory. Thus, a gradual reduction of technology-specific support is needed to avoid that the technology becomes dependent on permanent protection in narrow market segments (Smith & Raven, 2012). The second reason relates to the need to facilitate entry for newer alternatives with promising attributes. To avoid lock-ins and make room for promising new technologies, the actors involved thus have reassess past decisions (Boon & Bakker, 2016).

Building on evolutionary theories, system redeployment presents a possible solution to the conflicting recommendations in the literature on technological innovation systems and strategic niche management. System redeployment describes an alternative market formation process, different from the bridging recommendations, which are prevalent in theories on technological innovation systems. However, system redeployment cannot be reduced to market formation as a single TIS-process. Our case analysis shows how system redeployment
may depend on a number of different processes. This includes experimentation into new areas of application, knowledge development and diffusion to new actors, legitimation and mobilization of additional resources. In particular, the case analysis points at the variety of policy instruments required to influence search processes in new directions. Moreover it shows how system redeployment implies a significant change in the context and contextual interactions of a technological innovation system. Overall, the study points at the value of including patterns of interaction between systems in policy-oriented TIS-analyses. Technology-specific policies are crucial but carry a risk of creating increasingly path-dependent processes. This risk cannot be eliminated but policy makers and other key actors need to balance this risk with a learning capacity and openness that makes it possible to change direction and support several alternatives.

Acknowledgements

We are grateful for the constructive comments provided by two anonymous reviewers. The research received financial support from the Swedish Energy Agency and the Swedish Innovation Agency (VINNOVA), project number 2015-03536.

References


Maasing, U. (2016). Elbussar rycker allt närmare i Malmö (Electric buses are moving closer in Malmö). Bussmagasinet 31.5.


RS (2014). En strategisk agenda för innovation och utveckling av E-mobility i Sverige (A strategic agenda for innovation and development of E-mobility in sweden). Roadmap Sweden


SOU (2013). Fossilfrihet på väg (Freedom from fossil fuels on the road). Statens offentliga utredningar 2013:84


doi:http://dx.doi.org/10.1016/j.techfore.2009.03.002

doi:http://dx.doi.org/10.1016/j.eist.2013.10.001


Appendix A: Interviews

Unless otherwise stated, the interviews were semi-structured, face-to-face, and lasted 1–2h.

<table>
<thead>
<tr>
<th>Respondents</th>
<th>Organization</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy expert</td>
<td>K2 – Sweden’s national centre for research and education on public transport</td>
<td>2016-06-19 (by telephone)</td>
</tr>
<tr>
<td>Senior Manager Electric and Hybrid Powertrain Technology</td>
<td>Scania CV</td>
<td>2016-04-28 (by telephone)</td>
</tr>
<tr>
<td>CFO</td>
<td>Hybricon</td>
<td>2016-02-25</td>
</tr>
<tr>
<td>Key Account Manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head of Public Transport</td>
<td>Umeå municipality</td>
<td>2016-02-24</td>
</tr>
<tr>
<td>New Business Developer</td>
<td>AGA Gas AB</td>
<td>2016-02-12</td>
</tr>
<tr>
<td>Public Transport Coordinator</td>
<td>Malmö Municipality</td>
<td>2015-12-01</td>
</tr>
<tr>
<td>Project Manager Biogas</td>
<td>E.ON Gas Sverige AB</td>
<td>2015-12-01</td>
</tr>
<tr>
<td>Head of Business Development</td>
<td>Tekniska Verken</td>
<td>2015-05-11</td>
</tr>
<tr>
<td>Business Development Manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Responsible for procured public transport</td>
<td>The national association of bus operators</td>
<td>2014-11-14</td>
</tr>
<tr>
<td>Short interviews (5-20 minutes) with representatives for Bozankaya/Sileo, Ebusco, Opbrid, Magna, MAN, Mitsubishi Fuso, Scania, Solaris, VDL, Volvo and Ziehl-Abegg at IAA Nutzfahrzeuge in Hanover</td>
<td>2014-10-01/02</td>
<td></td>
</tr>
<tr>
<td>Head of E-mobility R&amp;D program</td>
<td>Vattenfall</td>
<td>2014-04-04</td>
</tr>
<tr>
<td>Project Coordinator</td>
<td>ElectriCity</td>
<td>2014-04-02</td>
</tr>
<tr>
<td>Postdoc Heavy vehicle charging systems</td>
<td>Chalmers University of Technology</td>
<td>2014-04-01</td>
</tr>
<tr>
<td>Environmental specialist</td>
<td>Schenker</td>
<td>2014-04-01</td>
</tr>
<tr>
<td>Business Developer</td>
<td>Göteborg Energi</td>
<td>2014-03-31</td>
</tr>
<tr>
<td>Environment Analyst</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head of Public Affairs</td>
<td>Volvo Bus Corporation</td>
<td>2014-03-05</td>
</tr>
<tr>
<td>Transport Solution Specialist</td>
<td>Volvo Group Trucks Technology</td>
<td>2014-03-05</td>
</tr>
<tr>
<td>Environment and Market Strategist</td>
<td>Region Västra Götaland: Public transport and infrastructure</td>
<td>2014-03-04</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>---------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Manager Advanced Technology R&amp;D Director Alternative Vehicle Efficiency</td>
<td>Volvo Group Trucks Technology</td>
<td>2014-03-03 and 2012-03-16</td>
</tr>
<tr>
<td>CEO (retired)</td>
<td>Volvo Group</td>
<td>2014-03-03</td>
</tr>
<tr>
<td>Senior Adviser</td>
<td>Volvo Group</td>
<td>2014-01-20</td>
</tr>
<tr>
<td>Vehicle Strategist</td>
<td>Stockholm County Council, Public Transport Administration</td>
<td>2013-06-05</td>
</tr>
<tr>
<td>R&amp;D Director</td>
<td>Scania CV</td>
<td>2013-02-07</td>
</tr>
<tr>
<td>Head of hybrid system development</td>
<td>Scania CV</td>
<td>2011-09-15</td>
</tr>
<tr>
<td>Bus Fleet Manager</td>
<td>Nobina</td>
<td>2011-03-30</td>
</tr>
</tbody>
</table>

**Appendix B: Workshops and seminars**

<table>
<thead>
<tr>
<th>Title/Topic</th>
<th>Organizer</th>
<th>Location</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing – Transition to a fossil free transport sector</td>
<td>The Swedish Energy Agency and The Swedish Transport Administration</td>
<td>Stockholm</td>
<td>2017-03-14</td>
</tr>
<tr>
<td>Dialogue meeting for a fossil free transport sector</td>
<td>The Swedish Energy Agency</td>
<td>Stockholm</td>
<td>2016-11-29</td>
</tr>
<tr>
<td>The ZeEUS Stockholm project</td>
<td>Volvo and Vattenfall</td>
<td>Stockholm</td>
<td>2016-06-02</td>
</tr>
<tr>
<td>Framing of and strategy for biogas solutions</td>
<td>BRC</td>
<td>Linköping</td>
<td>2016-05-26/27</td>
</tr>
<tr>
<td>National strategies for biogas development</td>
<td>BRC IP5 Regions</td>
<td>Linköping</td>
<td>2016-02-05</td>
</tr>
<tr>
<td>Electrified public transport</td>
<td>VTI Transportforum</td>
<td>Linköping</td>
<td>2016-01-13</td>
</tr>
<tr>
<td>Biogas experiences from municipalities and ongoing research</td>
<td>BRC</td>
<td>Linköping</td>
<td>2015-12-03/04</td>
</tr>
<tr>
<td>Electric bus plan Stockholm</td>
<td>ElectriCity and ElBil2020</td>
<td>Stockholm</td>
<td>2015-10-07</td>
</tr>
<tr>
<td>Title</td>
<td>Organization</td>
<td>Location</td>
<td>Date</td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>----------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Biogas sector development and the role of internal and external factors</td>
<td>BRC</td>
<td>Linköping</td>
<td>2015-05-28/29</td>
</tr>
<tr>
<td>How to speed up the implementation of electric buses</td>
<td>Vattenfall</td>
<td>Stockholm</td>
<td>2015-05-22</td>
</tr>
<tr>
<td>Challenges and possibilities for biogas in a regional context</td>
<td>BRC IP5 Regions</td>
<td>Linköping</td>
<td>2015-04-22</td>
</tr>
<tr>
<td>The innovation system for electrified heavy vehicles in urban traffic</td>
<td>The Swedish Energy Agency</td>
<td>Stockholm</td>
<td>2014-11-12</td>
</tr>
<tr>
<td>Electrified Public Transport</td>
<td>Lindholmen Science Park</td>
<td>Gothenburg</td>
<td>2014-05-21/22</td>
</tr>
<tr>
<td>Is the future electric? Future routes to energy efficient public transport</td>
<td>The national association of bus operators and BilSweden</td>
<td>Stockholm</td>
<td>2013-10-09</td>
</tr>
</tbody>
</table>