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Barriers to the diffusion of renewable energy: studies of biogas for transport in two European cities

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Abstract

The diffusion of renewable energy – particularly in transport – in cities may facilitate the transition away from fossil fuels, improve air quality and reduce greenhouse gas emissions. Past studies on this topic have focused on system modelling of diffusion pathways, technology characteristics and also estimations of future availability of renewable energy, whilst neglecting the agency of producers and users. This article assesses barriers to the diffusion of biogas for transportation in cities from a system and actor perspective. Using document studies and interviews in the cities of Basel, Switzerland, and Odense, Denmark, we identify the presence of conflicting political priorities and shifting strategic objectives, resulting in mixed signals concerning the role and viability of biogas for transportation. This underlines the importance of public sector support and coherent design and implementation of strategy and policy enabling the diffusion of renewable energy.

Keywords: Renewable energy; Diffusion; Cities; Biogas; Transport

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1. Introduction

There is widespread agreement among policy makers and researchers that a transition towards a low-carbon energy system is necessary albeit insufficient to tackle the challenges of climate change (WWF, 2014). Furthermore widespread and systemic changes in current technology, infrastructure, lifestyles, institutions and business models are necessary to facilitate such a transition (Boons et al., 2013; Rennings, 2000). To be specific the rapid development and diffusion of environmentally sound technologies for use in different societal contexts is deemed essential in such transitions towards sustainability (Rennings, 2014). This is particularly true for the transport sector, as a major consumer of fossil fuels and source of both greenhouse gas emissions, and for cities, where the negative impacts of motorised transportation have clear environmental, spatial and societal impacts (van Wee and Handy, 2016; Perez et al, 2015).

The pressing challenges of climate change, biodiversity loss, material and energy resource depletion and the quest for a transition to a post fossil-fuel society has stimulated widespread interest in renewable energy sources. Accordingly, recent studies have analysed the diffusion of such renewable energy technologies such as wind turbines, solar cells, hydrogen fuel cells and biomass digestion particularly in the early phases of their diffusion (Mignon and Bergek, 2015). The use of such renewable energy sources in transportation is particularly interesting since it can serve both as a climate change mitigation strategy, facilitate a transition towards fossil-independence, and improve air quality in cities and urban areas. However, the diffusion of such renewable fuels in transportation such as biogas (biomethane) has only been successful in some cities and faces many challenges (Fallde and Eklund, 2015; Olsson et al, 2015). This is also more generally the case for sustainable mobility in urban planning, as strategic objectives are often undermined by day-to-day decisions with resultant incrementalism or inaction (Hrelja, 2011).

Research on the diffusion of renewable biofuels for transportation has focused on policy measures to promote adoption among users, business models for the diffusion, socio-economic modelling and projections of their diffusion rates, estimates on their future availability (Fallde and Eklund, 2015; Kanda et al., 2015; Madlener and Schmid, 2009; Urban Wangler, 2013). However, an important aspect which has received limited research attention in the biogas diffusion literature is the agency of actors involved in the sector. In particular, the roles of producers and end-users in the diffusion of biogas as a transport fuels and how their actions and inactions are affected by the system within which they operate is the interest of this article.

Departing from this background and using empirical data from the European cities of Basel and Odense, this article analyses the barriers to the diffusion of biogas for transportation. In particular, we attempt to explain the system and actor-level challenges which have led to both cities making investment decisions favouring the use of diesel hybrid technology in their bus fleets even though they are full/part owners of biogas producing companies. Grounded on the theories of the diffusion of innovations with particular focus on the diffusion of environmental technologies, this article aims to explore the empirical and theoretical barriers to the diffusion of renewable transportation fuels – in particular biogas – in city contexts influenced by political priorities, perceptions about technology pathways, taxes and duties, production costs, and lack of consumer interest.

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2. Theoretical background

This section of the article provides a theoretical background through which the empirical data will be analysed. The section starts with a discussion on the broader concept of environmental technologies which encompasses the various technologies discussed in the empirical data. Thereafter, we narrow down to the factors influencing technology diffusion in general and environmental technology diffusion in particular. The section ends with a synthesis framework which is subsequently used to analyse the empirical data.

The concept of "environmental technology" seems easy to grasp at first hand but that is far from the truth. In fact, both in the academic and public discourse, there is no internationally agreed upon definition to the concept. Furthermore, the concept is used synonymously with several other concepts such as "cleantech", "green technology", "low carbon technology", "environmentally sound technology" but to name a few. In the academic discourse, key debates on the concept center on several aspects such as the intentionality or not of their environmental improvements, their particular characteristics which differentiates them from "other" technologies, and whether the concept encompasses both technological and non-technological aspects. Despite these differences, a defining characteristic of environmental technologies is their environmental improvements (Carrillo-Hermosilla et al., 2010).

For example, Kemp (1997, p.11) defines environmental technologies broadly as each "technique, process or product which conserves or restores environmental qualities". In the public discourse, the EU (2004, p.2) defines environmental technologies as: "all technologies whose use is less environmentally harmful than relevant alternatives. They encompass technologies and processes to manage pollution (e.g. air pollution control, waste management), less polluting and less resource-intensive products and services and ways to manage resources more efficiently (e.g. water supply, energy-saving technologies)". See (Guziana, 2011) for an extended review of the various definitions of the concept. In this article, we use a broader understanding of the concept as technologies (products, services, large technical systems, organizational and business models) whose development and use actually provide or are intended to provide a better environmental performance from a life cycle perspective compared to relevant alternatives. With this broad understanding of the concept, we embrace environmental improvements which are realized on purpose and those realized without the initial intention to do so and also both "hard" technological and "soft" non-technological aspects of the concept.

Technology diffusion describes the aggregate adoption decision by a population of potential adopters over time and influenced by a variety of factors which are difficult if not impossible to capture in entirety (Kemp and Volpi, 2008). There are several theories and models of the diffusion of technological innovations with some dating as far back as the 1950s (Sarkar, 1998). Some of these theories focus on the systemic factors while other are more directed at the actor-level and across different states of the innovation from nursing and bridging markets to the entire life cycle of the innovation. Everett Rogers is often considered as one of the seminal contributors to the diffusion of innovations in general. He introduced five dynamic aspects which influences rate of adoption of innovations (Rogers, 2010). These are:

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1. **Relative advantage**- the degree to which the innovation is considered to be better than the system it supersedes
2. **Compatibility**-the degree to which an innovation aligns with existing values and past experiences
3. **Complexity**-how difficult a solution is perceived to be
4. **Trialability**-the degree to which an innovation can be put to test on a limited basis
5. **Observability**-the degree to which the results are visible to others.

More recently there have been theoretical frameworks which build upon such seminal works but particularly targeted at environmental innovations. For example, (Beise and Rennings, 2005) introduce the concept of lead markets to analyse countries that first adopt a globally dominant innovation design, and thus enjoy leadership in the international diffusion through export of the innovation and by setting the global standard. They identify five advantages as influential in the creation of such lead markets for "environmental innovations":

1. **Price advantage** - arises from national conditions that results in relative reductions in the price of nationally preferred innovations compared to design preferred in other countries or in anticipation of international factor price changes
2. **Demand advantage** - originates from national conditions which result in the anticipation of the benefits of an innovation design emerging at a global level
3. **Transfer advantage**,- are national conditions that increase the perceived benefits of a nationally preferred innovation design for users in other countries.
4. **Export advantage** – constitute conditions which promote the inclusion of foreign demand preferences in nationally preferred innovation design
5. **Regulation** – refers to the international diffusion of regulations which foster the diffusion of the innovation

Departing from the systemic view, to the actor-level, (Fichter and Clausen, 2012) identify seven key factors of particular significance in the diffusion of "sustainability innovations". These factors are: (i) the market power of established providers, (ii) political push and pull, (iii) the influence of pioneers, (iv) purchase incentives, (v) compatibility with routines, (vi) price and economic viability and (vii) the transparency of innovation.

From a business perspective with a focus on technology suppliers, Kanda et al. (2015) present seven factors which influence the diffusion of large scaled environmental technology systems such as district heating, waste management and renewable energy systems:

1. **Market (with emphasis on regulation)** - a system through which producers and customers engage in exchanges.
2. **Finance** - covers both the cost incurred in creating customer value and the revenue obtained from delivering such value to customers.
3. **Resources** – Key resources refer to the technological, financial, and intellectual competence needed to exploit a business opportunity and to create customer value.
4. **Activities** – refers to the key activities that are undertaken to exploit the business opportunity and create customer value.

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5. **Partnership (with emphasis on Public-private partnership)** –covers key partnerships needed for the business model to function.
6. **Ownership and responsibility** –covers the assignment of responsibility for the technology during and after its use phase if applicable
7. **Legitimacy**- refers to social acceptance and the compliance with relevant institutions and regulations

Other recent scholarly contributions also synthesize both system-level and actor-level factors which influence the diffusion of environmental technologies. For example for the diffusion of renewable electricity technologies, Mignon and Bergek (2015) synthesize system and actor-level factors which challenge the diffusion of such technologies. These include:

1. **Market structure challenges**-relates to the market organization and structure which limits the possibilities of new entrants to gain foothold on the market.
2. **Infrastructure challenges**-relates to the lack of basic physical and non-physical infrastructure needed for various societal functions to operate.
3. **Financial Challenges**-caused by the relatively high investments costs in renewable energy technologies
4. **Institutional challenges**- occur when formal and informal “rules of the game” (e.g. laws, regulations, norms, values) influence selection to the disadvantage of new technologies
5. **Interaction challenges**-relates to too strong or too weak connectivity within the system which results in lock in or lock out of certain technologies
6. **Technology supply challenges**-are due to lack of competence, resources or capacity of the supply side
7. **Adopter resource challenges**-related to limited resources of adopters in terms of knowledge and experience, finance, physical and social capital which hinder technology adoption
8. **Behavioural challenges**- includes adopters characteristics such as motives, norms, values, strategies which can influence to what extent adopters are willing to invest in renewable energies.

For technology adopters, the decision to adopt an environmental technology is influenced by technical, socio-economic and institutional factors. Some scholars classify these factors as being internal and external example to an adopting firm. Internal factors include for example financial commitment, absorptive capacity, technical competency, skilled labour force and top management commitment. Other factors external to the firm include regulation and pressure from networks and competitors (del Río González, 2005).

<< Insert Table 1 here >>

These previous contributions present factors which influence the diffusion of environmental technologies in general from the perspective of the technology supplier and adopter and also from a systemic and actor-level. Table 1 above synthesizes the aspects from their previous literature which could be employed in the analysis of the diffusion of renewable energy technologies. Based on the empirical data we have from the two cities and also the major themes emerging from the interviews, we will employ two key aspects explicitly in our analysis i.e. (i) system-level challenges (ii) actor-level

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challenges. Furthermore, the authors acknowledge that, the other aspects from the synthesis such as technology characteristics and business aspects are important in the diffusion of such technologies, such analysis is out of our main focus in this article and has also received recent scientific attention (Flodén and Williamsson, 2015; Kanda et al., 2015; Mejía-Dugand et al., 2013). These aspects will be integrated and highlighted in the analysis as and when necessary.

3. Methods

This study was conducted using qualitative research methods and the results and analysis are primarily based on interviews conducted during the project. Prior to the interviews, a wide-ranging document study was conducted, addressing themes including sustainable urban development strategy and policy in the studied cities, plus related regional and national frameworks and initiatives (e.g. industry biogas initiatives). During the course of the document study, potential interviewees were identified and contacted, and a semi-structured interview guide was developed.

A mix of individual and group interviews were held with representatives of different organisations (see Table 2). Three interviews in Odense were held in March 2015 – one group interview with three municipal civil servants; one with a civil society representative; and one with a representative from a gas company that is co-owned by several municipalities, including Odense. In addition, a municipal politician provided answers to written questions, giving a total of six respondents. Three of the interviewees worked either directly or on the political or strategic levels with issues related to renewable energy, biogas or public transport, whereas the other interviewees worked more closely with mobility, transport and urban planning.

In Basel, five interviews were held with eight individuals from seven organisations during April 2015. The interviewees included three cantonal civil servants from two cantonal departments; two local politicians from different political parties; two representatives of civil society groups; and a representative of the municipal utilities company. As in Odense, this group was divided evenly between those working directly or on the political or strategic level with issues related to renewable energy, biogas or public transport, and those working with mobility, transport and urban planning.

<< Insert Table 2 here >>

A wide range of themes were discussed during the interviews, ranging from for example politics and decision-making, constitutional affairs and legal frameworks, working methods, organisation, to consultation and cooperation. Interviewees were granted anonymity and are referred to in the text by type (i.e. Civil servant; Civil society; Company; Politician – see Table 2). All interviews were transcribed in full and the contents logged into excel sheets. This provided a framework for structured thematic analysis, the results of which follow.

It should be noted that the primary objective of this paper is not to provide comparative analysis, but rather to investigate what appear to be contradictions or conflicts in city strategies for sustainable urban development, with special focus on the use of renewable energy and in particular biogas. As such, the primary focus of the paper is on Basel, the city for which we have (a) more empirical data and (b) a wide range of topics to discuss. Material from Odense is introduced to describe and

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illustrate what appear to be similar trends or challenges, which – when taken together with our findings in Basel – inform our analysis and conclusions.

4. Results

In the following section, we present findings from Basel, with a short background on the city prefacing an overview of renewable energy strategy and policies. This includes discussion of renewable electricity, district heating, and the role of biogas in heating and transportation. Thereafter follows a shorter overview of findings concerning the role of biogas in Odense.

4.1. Experiences from Basel

4.1.1. Background

The city of Basel, Switzerland is located at the heart of a trinational agglomeration of 900,000 inhabitants, comprising 250 French, German and Swiss municipalities. The canton Basel-Stadt is a densely-populated urban conurbation formed of three municipalities – Basel Stadt (175,000), Riehen (21,000) and Bettingen (1,200); much of the city's rural hinterland is located in a different canton, Basel-Landschaft and other parts of the agglomeration. As Switzerland is a confederation and cantons have strong degrees of autonomy, this means politics in Basel-Stadt has a strong focus on urban affairs within the city of Basel. At the same time, numerous cross-border issues affecting the city mean that various forms of national or international cooperation are required.

Swiss cantons have their own constitutions and are parliamentary democracies. In Basel, an Executive of seven members, representing different parliamentary parties, is selected to govern and each individual member is given responsible for a different portfolio (and in turn, department). In addition, there are various parliamentary commissions – including the Environment, Transport and Energy Commission – that for example, provide oversight, make proposals and interpellations on themes including energy and transport.

Within the cantonal administration, climate change and renewable energy – along with issues including air quality, environmental remediation, noise abatement, waste management, water quality – is the responsibility of the Office for Environment and Energy, a division of the Department for Economic, Social and Environmental Affairs. The overall responsibility for transport is located at the Office for Mobility of the Public Works Department overseen by a different Executive member to Economic, Social and Environmental Affairs.

The major utilities provider in Basel is the canton-owned company IWB (Industrielle Werk Basel). IWB has a wide portfolio and provides regional services for biogas and natural gas, district heating, electricity, electric mobility, energy (efficiency) services, telecommunications, and drinking water. IWB has production facilities in other parts of Switzerland, countries including France (solar, wind), Germany (biogas, wind) and Spain (solar) and, following a cantonal ruling, IWB aims to phase out fossil and nuclear fuels from its energy portfolio (IWB, 2013).

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4.1.2. Renewable energy in Basel – an overview of strategies and policies

During the course of the interviews, respondents provided a range of perspectives on renewable energy strategy and policy in Basel and its links with other themes, including climate change and environmental protection. In the following section, a summary of key points from these discussions prefaces a more detailed presentation of respondents' views concerning biogas and its role in cantonal work for climate, energy and transport.

Renewable electricity

On a general level, respondents highlighted some of the aforementioned points concerning the cantonal system and organisational structure, and IWB and its portfolio (Civil servant; Politician). For example, one respondent explained how IWB was spun out of the cantonal administration in 2010 and outsourced as a municipally-owned company. During this process:

“one of the details was... we can make some parameters to define what they have to do. One of the parameters was... only renewable electricity, no other will be sold. So that way, no nuclear power, no gas, it's no question, they are not allowed to. So doing that, outsourcing a company, they have no choice.” (Politician)

The decision to outsource the company –partly on the basis that it enables the clear definition of their role and mandate – implies that, to some extent, this was not possible when the operations were part of the cantonal administration.

However, another respondent suggested that the decision to only distribute renewable electricity must be seen in its wider context, remarking that:

“the only part where we are a little bit further than other cities in Switzerland is the electricity production, so we have 100% renewable electricity. But this is just on paper, a calculation, as electricity is always a mix and in Switzerland we have all kind of mix, but what we need in Basel we produce renewably in Switzerland or in our plants where we are part of the production.” (Civil servant)

In other words, 100% renewable electricity means that IWB own facilities – including e.g. hydropower in Switzerland and wind farms in France – producing a total volume equivalent to the amount used in the canton (Civil servant; Politician). This electricity enters the grid in different locations across Europe and effectively offsets the real mix used in Basel (Civil society).

District heating

The same principle of production elsewhere offsetting local consumption also applies to natural gas (Civil society). However, just as “setting this parameter for electricity was easy...” it is “quite challenging” to apply the same logic to Basel's extensive district heating network (Politician), the largest of its kind in Switzerland. Another respondent remarked “we have 100% electricity renewable, but in the heating system we still have a lot of gas, and this is not biogas”, although wood-based biomass is accounting for an increasing share of district heating production (Civil servant). Interviewees suggested renewables account for approximately 50% of heating production

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and Basel's strategic aims for district heating include increasing this share, whilst continuing to expand the network and increase the energy efficiency of buildings). This means, for example, the Office for Environment and Energy and IWB must increasingly step into the realm of urban planning (overseen by the Public Works Department) in order to realise its objectives (Civil servant). A recent law obliges new construction or renovation of industrial or residential buildings to include energy efficiency measures and solar photovoltaics or other renewable production that provide at least 50% of water heating. A funding programme was established by the Parliament to facilitate implementation of this law (Civil servant; Politician).

Biogas in heating: barriers and opportunities

The low price of natural gas is cited as a barrier inhibiting a transition to other energy sources, particularly for private households not connected to the district heating network. Moreover, the organic waste fraction is not efficiently sorted during waste management (Politician) and could possibly be used more efficiently to produce biogas (Civil servant). The scarcity of waste means – if the organic fraction were to be used for increased biogas production – that IWB faces either increasing imports of waste or possibly downscaling the district heating system; alternatively, a major energy efficiency initiative would be required. Each alternative throws up challenging questions regarding the systems effects of supposedly sustainable socio-technical systems such as district heating, but these are outside of the scope of this paper.

Aside from its potential utility as a replacement for fossil natural gas in the district heating system, the possibility that biogas could be used for energy storage was raised:

“one big problem in the district heating system... (is) that in summer we have a lot of heat and in winter we need more heat... biogas could be just one solution, because to store biogas is very easy. To store waste is maybe a little bit more difficult, then you need more room.” (Civil servant)

Thus, one perspective on biogas is that, by removing the organic waste fraction (approximately 30% of total waste) from incineration to produce biogas and store it, there may be scope to achieve seasonal improvements and thereby overall system performance will be increased. However, according to a representative of IWB, under present circumstances “biogas 100% is too expensive for our clients” (Company).

The high cost of biogas production means that IWB “can't really substitute natural gas with biogas...” despite their “... strategy to actually build more plants” without changes to the overall demand picture (Company). Partly for this reason, on 1 May 2015, IWB introduced a 3% share of biogas into their standard natural gas product for private households (IWB, 2014). This change was a management-level decision linked to IWB's production strategy from 2012, which led to investments in new production facilities (Company). This meant that IWB increased its biogas production from 3GWh to around 30-35GWh and needed a market for the increased volumes.

As a result, the product, 'Bio-Erdgas' (97% natural gas, 3% biogas) has replaced natural gas as the company standard. However, both 100% natural gas and various 'Biogas Plus' products, ranging from 5% to 100% biogas blends, are available for consumers to select from. Future studies have the

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possibility of exploring the impacts of this change. However, a curious detail is that, from 31 March 2015, the price of 100% natural gas was reduced (the Company representative linked this to currency changes and international prices for natural gas products). From 1 May 2015, a new price system came into force, reducing prices for customers choosing fossil natural gas or low biogas blends, yet increasing prices for customers selecting higher biogas blends (IWB, 2015). In effect, this new pricing system penalises efficient users of high blend biogas products in favour of those using fossil natural gas, inverting the 'polluter pays' principle, even as it simultaneously increases the overall level of biogas consumption in Basel.

Another challenge for IWB concerns the communication of information concerning biogas, not least as some of the production is based in Germany. This means that biogas is fed into the natural gas grid and Basel, as described above, counts an equivalent volume of consumption to have been offset by this production. However, this inhibits certification with the Swiss organisation Nature Made – who do not recognise biogas from Germany – and also subjects the product to import duties, carbon taxes, etc. (Company). With limited opportunities to increase production in Switzerland (with the exception of the organic waste fraction described above), this is perhaps the only viable route for IWB to pursue. Nevertheless, it creates a conceptual challenge as "there's people who don't think that makes sense" (Company).

Biogas in transport: setbacks and stagnation

Despite expanding production in Switzerland, the increasing interest in use of biogas in heating may mean that the outlook for use of biogas in transportation in Basel appears limited. This is curious, as Basel's initial decision to construct biogas production facilities was motivated by the desire "to produce biogas for the transport department of Basel, to have biogas for their buses", an ambition that has been met through incremental steps (Company). Moreover, in 2010 a network of fuel stations for gas-driven vehicles was launched in Switzerland, offering a minimum 10% and average 20% biogas blend (Verband der Schweizerischen Gasindustrie, 2015).

Basel introduced gas-driven buses to the public transport fleet in 2008 in part to replace the city's electric trolley bus network. Interviewees described this as an example of a decision following pressure from interest groups using misleading arguments (e.g. trolley buses are inflexible compared to conventional buses) and in spite of lack of biogas; and claimed that although the decision was initially popular, it has since been proven misguided (Civil society; Politician; Company). Irrespective of the merits of this argument – and it seems there are some, given the fact that Basel has an extensive tram network which the trolley buses also used (with associated benefits in terms of air and noise pollution compared to conventional buses) – gas-driven buses were procured on the basis that they could be operated using biogas. IWB signed a contract to deliver biogas to the public transport fleet for the period up until 2020 and developed its biogas strategy partly in relation to this contract (Company). However, by 2014, the share of biogas in the vehicle fuel was only 36% (Oggier, 2014).

Nevertheless, in 2014, the administration decided to purchase new diesel-electric hybrid buses and phase out the biogas buses. This sparked a political initiative to phase out fossil fuels from public transport (Civil society; Politician; Company). Moreover, the decision means that, as IWB increases

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its biogas production, in part to supply the bus fleet, the long-term commercial viability of the necessary production facilities may be jeopardised (Civil servant). Whilst the decision to focus on diesel, hybrid technologies and a pathway to electrical transportation may be in some senses understandable, the series of shifts from trolley buses to biogas and now diesel creates uncertainty and challenges; it also may explain the "sudden" shift in strategy at IWB and its introduction of the Bio-Erdgas standard for heating (Company).

In addition, developments at the national level have also created uncertainty regarding the role of biogas and natural gas in vehicle fuels. A series of national initiatives, incentive schemes and investments in fuel stations failed to stimulate gas vehicle sales. On the contrary, sales of gas as vehicle fuel declined and, as a consequence, IWB decided to down-prioritise issues related to gas and mobility (Company). A combination of consumer uncertainty concerning gas vehicles and fuelling infrastructure, together with the emergence of electric vehicles was cited as one possible explanation for the decline in gas vehicle and fuel sales (Company).

4.2. Experiences from Odense

4.2.1. Background

Odense has a similar number of residents (196,000) to Basel, albeit residing in a larger area and a single administrative unit, the municipality of Odense. The city of Odense is the regional centre of the island of Fyn and is Denmark's fourth largest city.

Danish municipalities have a broad range of powers and responsibilities. Odense has an elected council of 29 members, who in turn are selected to work in five commissions. The Chairperson of each commission is responsible for the corresponding municipal administration (e.g. the City and Culture commission's chair has responsibility for the City and Culture Administration). Civil servants working in the administrations are organised by divisions and unit. For example, within the City and Culture Administration are five divisions (e.g. Business and Sustainability, or Urban Development), each composed of several units (e.g. Urban Development is comprised of Urban Planning, Mobility and Urban Space, and Property Development and Sales) (Odense Kommune, 2015).

The municipality of Odense is co-owner of NGF Nature Energy along with the seven other municipalities of Fyn. This company was once a regional company but now sells natural gas, biogas and energy services across Denmark. Odense is the largest shareholder, with a 25.7% stake and two board members (of a total 12), including the city's Mayor. The company has built biogas production facilities, which feed into the natural gas grid and supply households, industrial clients and transport fuel. In 2011, the company launched Denmark's first gas-powered vehicle fleet (NGF Nature Energy, 2015).

4.2.2. Biogas in Odense – a summary of the interview results

The interviews in Odense were less comprehensive concerning the role of biogas in the energy system and largely focused on the role of biogas as a transport fuel. With regard to energy, a few general observations could be made, such as, for example, the fact that there are a small number of biogas production facilities at wastewater plants, and these are typically used to power turbines and

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thus produce electricity and district heating. Farm-based biogas production is subsidised yet logistics costs inhibit the scaling up of production where distances are too large. Concerning organic waste, lack of consumer interest (i.e. large agricultural firms) in bio-fertilisers and poor separation of waste fractions (i.e. organic waste being used for incineration to power district heating systems) were cited as two barriers to market development (Company).

Turning to transport, NGF Nature Energy produces transport fuel under the name 'bio-natural gas'. This means that the company injects biogas into the natural gas grid and provides certificates verifying the CO₂ neutrality of sold products – an approach not dissimilar to that of IWB in Basel. The company considers some of the institutional conditions for biogas to be good, e.g. that the natural gas grid exists and fuel stations can form part of a wider network, rather than be located in isolation (Company). The company is also constructing new biogas production facilities in order to meet any short-term increase in demand for its product. Investments in production facilities and distribution networks mean that the company must identify clients that are able to provide "a certain security of the baseload for at least a certain period and a certain amount of the baseload per year". As such, municipalities are considered "the key for developing this market..." as they "...are not business case driven..." and "...an always pay that additional price and take it back in taxation" (Company).

In contrast, high levels of tax on natural gas and the low price of diesel and gasoline – as well as a limited if increasing range of vehicles on the market – act as disincentives to private fleet owners thinking of investing in gas-fuelled vehicles, suggesting the need for an overhaul of policy instruments (e.g. interviewees suggested the use of specific requirements in planning of new developments or changes to taxation). Moreover, CO₂ taxes apply not only to natural gas, but also to bio-natural gas as it is supplied by the same grid, undermining the purpose of NGF Nature Energy's certification system. A similar challenge was observed in Basel.

However, as noted above, municipalities are investing in gas-fuelled vehicles and bio-natural gas, particularly municipalities that are spatially large or have significant rural populations. In such contexts, small gas-fuelled vehicles provide an attractive alternative to electric vehicles. One municipality issued a call for tenders for waste collection services stipulating that only offers including gas vehicles would be considered and aim to progressively phase in gas vehicles in other tendering processes. In addition, some larger cities are considering use of biogas buses. One interviewee remarked "in general, the municipalities... choose between diesel or biogas" (Company).

Given this context and Odense's stake in NGF Nature Energy, one may expect the municipality of Odense to invest in gas vehicle fleets. However, in a 2014 procurement of new buses for use in public transport, the municipality rejected biogas in favour of diesel-hybrid bus technology. According to our interviewees, this reflected both the price of hybrid buses and political concerns about the level of PM in parts of the city centre. Local environmental concerns (in areas where buses travel at low speed) were thus prioritised above global concerns about greenhouse gas emissions and – more curiously – the potential benefits to a biogas-producing company co-owned by the municipality and supplying CO₂ neutral bio-natural gas. Moreover, the municipality favours use of electric vehicles rather than gas-driven cars for municipal services. However, the political decision to prioritise electric and hybrid vehicles at the expense of biogas – and to use the produced biogas for heating instead –

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places a limitation on the possibility for “private cars running on natural gas, which could be a side benefit much bigger” than potential greenhouse gas reductions from the municipal or public transport fleets (Civil servant).

5. Concluding discussion

As indicated in the introduction, this article aims to explore challenges in the adoption of biogas – and more specifically, biogas for transportation – by analysing the cases of Basel, Switzerland, and Odense, Denmark. From the theoretical background and the empirical data presented, the challenges in the diffusion of biogas can be discussed from various perspectives. These include for example the system and actor-levels, technology and business aspects. Nonetheless, the empirical data allows us to focus on certain aspects which will play more central roles than others. It should be noted however that, these categories are rather conceptual to allow for analysis and that in practise many of these aspects interact with each other. As depicted in Table 3 below, our main levels of analysis are the system and actor level challenges with corresponding examples from the studied cities.

<< Insert Table 3 here >>

The various connections between the theoretical background and the empirical data abstracted in Table 3 above are further discussed in detail in the following sub-sections.

5.1. *System-level challenges*

A well-discussed challenge in the adoption of environmental technologies (and for biogas) is their nature as public goods, which often generates externalities. An externality represents an economically significant effect of an activity, the consequences of which are borne (at least in part) by a party or parties other than the party that controls the externality producing activity (Jaffe, 2005). In the adoption of biogas as a transportation fuel, externalities relate to the fact that in the studied cities, the economic system favours natural gas for heating and diesel for transportation over biogas (for either and both). Specifically, in both cities it is cheaper to use fossil-based fuels for heating and transportation than to use biogas. Even though the use of renewable biogas could potentially result in lower emissions of greenhouse gases or local air pollution than fossil-based fuels, those private actors who chose to adopt biogas solutions for such purposes will do so at a relatively high economic cost, whereas the potential environmental benefits are system-wide and of a public nature. Thus, there is a clear need to strengthen or reorient strategies and policies to facilitate a shift from fossil fuels to renewable alternatives.

Both cities are attempting such transitions, although institutional challenges to the adoption of biogas as a transportation fuel emerge as a recurring insight from interviews in both cities. Particularly consistent institutional dimensions such as policy frames, laws and regulation have been mentioned several times in the literature as important in the adoption of environmental technologies (Río et al., 2015). However, in the studied cases, we observe unstable regulations and policies, with evidence of ad hoc planning that leaves conflicting priorities unresolved (Hrelja, 2011), e.g. concerning the cities' ownership of companies producing biogas for transport fuel and the selection of non-biogas alternatives for the city bus fleets.

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Changing political priorities have meant that, in both cities, diesel hybrid alternatives to biogas buses were selected in recent procurement processes. Such decisions have been motivated in part by arguments concerning local air quality, but also as part of a wider shift towards technologies that appear to facilitate transitions to electric vehicle pathways. Thus, immediate concerns regarding local air pollution and the possibility of learning about electric or hybrid technology weigh higher than concerns about the long-term impact of global greenhouse gas emissions and uncertainties concerning electric vehicles technologies. Moreover, the decision to focus on certain forms of electric vehicle pathways implies a rejection of other technology types – including both biogas buses and electric trolley buses – rather than the emergence and consolidation of a palette of complementary non-fossil alternatives (a trend considered negative in recent literature, e.g. Olsson et al, 2015).

5.2. Actor-level challenges

Such decisions directly influence the current and future revenue streams and development opportunities of municipally-owned companies that have invested in production and upgrading facilities for biogas. For example, the reluctance of IWB to significantly advance its work on biogas for transportation and instead focus on biogas blends in heating is in part a response to (a) the decision to phase out biogas buses, (b) dawdling demand from private consumers in the transport sector, and (c) the need to get a return on sunken costs.

Whilst some of the logic influencing recent decisions in both cities may be understandable – for example, it may be the case that the functionality or utility of biogas buses increases outside of urban areas, or that biogas is more “cost-efficient” when used in heating – it is also the case that mixed signals may undermine market development, both in terms of transportation, but also in terms of wider system challenges (e.g. incineration of organic waste). One interviewee in Basel remarked: “I am convinced that we have to think about not only energy efficiency or economic efficiency but also resource efficiency and this is where I want to get in the future” (Civil servant). If Basel were to more explicitly demonstrate demand for biogas, production may be incentivised and this in turn may generate spill-over effects (such as separation of the organic waste fraction prior to incineration) and contribute to diffusion in other contexts (e.g. increasing other consumer groups’ confidence in biogas as a transport fuel, both in terms of performance and security of supply). In this regard, despite Odense’s non-procurement of biogas buses, the municipally-owned company NGF Nature Energy experiences increasing interest from other municipalities and to a lesser extent, private actors.

Other challenges to the adoption of biogas as a transportation fuel include difficulties faced by actors involved in the transportation system. For example, the biogas producers face financial penalties when injecting biogas into the natural grid. As indicated from the interviews, IWB produces biogas at sites in Switzerland and Germany, yet the German biogas is subject to import duties during transportation to Switzerland (Company). This increases the relative price disadvantage of biogas when compared to fossil fuels. Moreover, the behaviour of potential adopters to biogas has a strong influence on how biogas diffuses. As indicated by (Rogers, 2010), the reception given to a technological solution depends on its characteristics such as how the innovation aligns with existing values and past experiences-compatibility.

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Our interviews suggest that there remains scepticism among potential customers towards gas vehicles and filling stations based on issues of safety, reliability and availability. For example, in Switzerland, incentive schemes supporting the purchase of new gas vehicles appear to have had limited impact on demand. Considering this point, it may be important for influential actors seeking to increase use of biogas in transportation – such as the municipalities owning biogas fuel-producing companies – to demonstrate the potential of biogas vehicles in a systematic way, rather than to disengage from the technology whilst expecting others to embrace it. As noted above, markets are sensitive to mixed signals and clear public sector support, provided in various forms, can play an important role in facilitating transitions to renewable energy (Urban Wangler, 2013).

5.3. Conclusions

Throughout this paper, we have tried to assess the factors influencing the diffusion of environmental technologies, with special focus on the topic of biogas and particularly biogas for transportation. To do so, we presented findings from interview studies in two cities, Basel and Odense, which are full or co-owners of companies producing and distributing biogas for end use in heating and transportation. In both cities, we see the presence of similar system-level challenges and actor-level challenges.

At the system-level, we identify the presence of conflicting political priorities and shifting strategic objectives, resulting in mixed signals concerning the role and viability of biogas for transportation. Investment decisions indicate a preference to pursue electric vehicle pathways, albeit in an inconsistent manner (e.g. the exclusion of electric trolley buses and adoption of greenhouse-gas emitting diesel hybrid vehicles as short-medium term bridge solutions) and at the expense of biogas and other renewable fuels. This, in both cities, occurs despite the cities' stakes in biogas-producing companies and investments in fuel stations, etc.

In sum, at the system-level, the cities appear to consider biogas as an inappropriate fuel for urban public transportation (in terms of factors such as local air pollution or noise) yet an appropriate fuel for regional/rural transport in other municipalities, for freight transportation, and for private vehicle owners. However – at the actor-level – interviewees indicated that as the private sector (e.g. freight, private individuals) is generally unwilling to bear the costs of a transition to biogas in transportation, municipalities and other public sector bodies must play a leading role as adopters, something Basel and Odense – despite their investments – appear unwilling to do. Some of the reasoning influencing this decision may be sound; yet it also appears perverse, and sends profoundly mixed signals to the market and creates an additional barrier to the diffusion of biogas in transportation.

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7. References

- Beise, M., Rennings, K., 2005. Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations. *Ecological Economics* 52, 5-17.
- Boons, F., Montalvo, C., Quist, J., Wagner, M., 2013. Sustainable innovation, business models and economic performance: an overview. *Journal of Cleaner Production* 45, 1-8.
- Carrillo-Hermosilla, J., Del Río, P., Könnölä, T., 2010. Diversity of eco-innovations: Reflections from selected case studies. *Journal of Cleaner Production* 18, 1073-1083.
- del Río González, P., 2005. Analysing the factors influencing clean technology adoption: a study of the Spanish pulp and paper industry. *Business strategy and the environment* 14, 20-37.
- EUCOM, 2004. Stimulating Technologies for Sustainable Development: An Environmental Technologies Action Plan for the European Union.
- Fallde, M., Eklund, M., 2015. Towards a sustainable socio-technical system of biogas for transport: the case of the city of Linköping in Sweden. *Journal of Cleaner Production* 98, 17-28.
- Fichter, K., Clausen, J., 2012. Diffusion paths of sustainability innovations. *Borderstep*, Berlin, p. 6.
- Flodén, J., Williamsson, J., 2015. Business models for sustainable biofuel transport- The potential for intermodal transport. *Journal of Cleaner Production*.
- Guziana, B., 2011. Is the Swedish environmental technology sector 'green'? *Journal of Cleaner Production* 19, 827-835.
- Hrelja, R., 2011. The Tyranny of Small Decisions. *Unsustainable Cities and Local Day-to-Day Transport Planning, Planning Theory & Practice*, 12:4, 511-524.
- IWB, 2013. IWB Renewable Power AG Jahresbericht, 2013. Basel: IWB.
- IWB, 2014. Nachhaltigkeit Berichterstattung 2014. Basel: IWB.
- IWB, 2015. Unser neuer Standard: IWB Bio-Erdgas. Basel: IWB.
- Jaffe, A. B., Newell, R. G., Stavins, R. N., 2005. A tale of two market failures: Technology and environmental policy. *Ecological economics*, 54(2), 164-174.
- Kanda, W., Sakao, T., Hjelm, O., 2015. Components of business concepts for the diffusion of large scaled environmental technology systems. *Journal of Cleaner Production*.
- Kemp, R., Volpi, M., 2008. The diffusion of clean technologies: a review with suggestions for future diffusion analysis. *Journal of Cleaner Production* 16, S14-S21.
- Kemp, R., 1997. *Environmental Policy and Technical Change*. Edward Elgar, Cheltenham.
- Madlener, R., Schmid, C., 2009. Spatial diffusion of biogas technology in Switzerland: a GIS-based multi-agent simulation approach. *International Journal of Environment and Pollution* 39, 28-43.

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<http://www.tandfonline.com/doi/full/10.1080/09640568.2016.1176557>

Mejía-Dugand, S., Hjelm, O., Baas, L., Ríos, R.A., 2013. Lessons from the spread of bus rapid transit in Latin America. *Journal of Cleaner Production* 50, 82-90.

Mignon, I., Bergek, A., 2015. System-and actor-level challenges for diffusion of renewable electricity technologies: an international comparison. *Journal of Cleaner Production*.

NGF Nature Energy, 2015. Available at: <http://www.natureenergy.dk/om-os/ejerforhold/> (accessed 14 December 2015).

Odense Kommune, 2015. Available at:

<http://www.odense.dk/sitetools/om%20kommunen/forvaltninger> (accessed 14 December 2015).

Oggier, M. 2014. Bus der Zukunft. Presentation to Clean Fleets National Workshop Freiburg, 5 December 2014. Available at: http://www.clean-fleets.eu/fileadmin/files/documents/National_Workshops/FreiburgNW/Bus_der_Zukunft_Pr%C3%A4sentation_6_Homepage.pdf (accessed 16 December 2015).

Olsson, L., Hjalmarsson, L., Wikström, M., Larsson, M., 2015. Bridging the implementation gap: Combining backcasting and policy analysis to study renewable energy in urban road transport. *Transport Policy*, 37, 72–82.

Perez, L., Trüeb, S., Cowie, H., Keuken, M.P., Mudu, P., Ragettli, M.S., Sarigiannis, D.A., Tobollik, M., Tuomisto, J., Vienneau, D., Sabel, C., Künzli, N., 2015. Transport-related measures to mitigate climate change in Basel, Switzerland: A health-effectiveness comparison study. *Environment International*, 85: 111-119.

Rennings, K., 2000. Redefining innovation—eco-innovation research and the contribution from ecological economics. *Ecological Economics* 32, 319-332.

Rennings, K., 2014. Introduction: Global diffusion of environmental innovations. *Environmental Innovation and Societal Transitions* 10, 1-3.

Río, P.d., Peñasco, C., Romero-Jordán, D., 2015. What Drives Eco-innovators? A critical review of the empirical literature based on econometric methods. *Journal of Cleaner Production*.

Rogers, E.M., 2010. *Diffusion of innovations*. Simon and Schuster.

Sarkar, J., 1998. Technological diffusion: alternative theories and historical evidence. *Journal of economic surveys* 12, 131-176.

Urban Wangler, L., 2013. Renewables and innovation: did policy induced structural change in the energy sector effect innovation in green technologies?, *Journal of Environmental Planning and Management*, 56 (2), 211-237.

van Wee, B., Handy, S., 2016. Key research themes on urban space, scale, and sustainable urban mobility, *International Journal of Sustainable Transportation*, 10(1), 18-24.

This is an early version of the article "**Barriers to the diffusion of renewable energy: studies of biogas for transport in two European cities**". The definitive version of the article was published in Environmental Planning and Management and is available at:

<http://www.tandfonline.com/doi/full/10.1080/09640568.2016.1176557>

Verband der Schweizerischen Gasindustrie, 2015. Erdgas und Biogas als Treibstoff 1998 - 2010, Available at: <http://www.erdgasfahren.ch/fahren/hintergrund-erdgasbiogas/> (accessed 9 December 2015).

WWF, 2014. The Global Cleantech Innovation Index 2014. Cleantech group LLC; WWF.

This is an early version of the article "**Barriers to the diffusion of renewable energy: studies of biogas for transport in two European cities**". The definitive version of the article was published in Environmental Planning and Management and is available at:

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Table 1. Synthesis of factors influencing the diffusion of environmental technologies

Literature review	1. Diffusion of innovations (Rogers,2003,2010) 2. Lead markets for the diffusion of environmental innovations (Beise and Rennings, 2005) 3. Factors influencing the adoption of environmental technology (del rio Gonzalez,2010) 4. Key factors in the diffusion of sustainability innovations (Fichter and Clausen, 2012) 5. Business aspects in the diffusion of environmental technology systems (Kanda et al., 2015) 6. System and actor-level factors in the diffusion of renewable energy technologies (Mignon and Bergek, 2015)		
Synthesis of factors influencing the diffusion of environmental technologies			
Technology characteristics	System-level challenges	Actor-level challenges	Business aspects
<ul style="list-style-type: none">Relative advantageCompatibilityComplexityTrialabilityObservability	<ul style="list-style-type: none">Market structureInfrastructureFinancialInstitutionalInteractionRegulations	<ul style="list-style-type: none">Technology supply challengesAdopter resource challengesBehavioural challenges	<ul style="list-style-type: none">Market (including regulation)FinanceResourcesActivitiesPartnership (including private-public partnership)Ownership and responsibilityLegitimacy

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Table 2. Overview of interviews and interviewees.

	Basel			Odense		
Category	Organisation	Individual / group	Total persons	Organisation	Individual / group	Total persons
Civil servant	Canton Basel-Stadt (Dept. of Economic, Social & Environmental Affairs; Dept. of Public Works)	1 Ind.; 2 persons in group A	3	One municipal department (City and Culture Administration)	Group (3 persons)	3
Politician	Social Democratic Party; Green Party	1 Ind.; 1 person in group B	2	Liberal Party	Written response	1
Civil society	Two transport NGOs	2 persons in group B	2	Transport NGO	1 Ind.	1
Company	Energy company	Ind.	1	Energy company	Ind.	1

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Table 3. Connections between the theoretical background and the empirical cases

Level of analysis	Main category of challenge	Examples from Basel and Odense cases
System level	Market structure challenges	Relatively higher prices of biogas as vehicle fuel and for heating
	Institutional challenges	Unstable regulations and policies; conflicting priorities; changing political priorities
Actor level	Technology supplier challenges	Financial disincentives for injecting biogas into natural gas grid
	Behavioural challenges	Scepticism among potential customers on the safety of (bio) gas vehicles and filling stations