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Diffusion of biogas for freight transport in Sweden: A user perspective

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ABSTRACT

Current freight transport is highly dependent on fossil fuels and there is a need for a transition to alternative fuels and technologies. Biogas is a type of biofuel that has the potential to reduce climate emissions from freight transport, while providing additional benefits such as recycling of nutrients and increased energy security. This paper uses theories on the diffusion of green technologies to analyse the barriers and drivers for the increased use and diffusion of biogas in freight transport. The empirical focus is on the region of Västra Götaland in Sweden, and qualitative interviews have been conducted with demand-side actors such as transport buyers, haulage companies and vehicle manufacturers. The results confirm the important barriers observed in previous research, such as the higher costs of biogas, financial uncertainties and lack of infrastructure, as well as the interplay between barriers. The main drivers are an increased focus on sustainability both within the sector and from wider society, as well as the environmental properties of biogas. Specific barriers have also been identified such as a fragmented freight market structure with a mix of large and small transport companies, tight profit margins and reduced capacity for investments. There is also a division of labour and responsibilities between transport companies and transport buyers, which makes it unclear who will drive the transition to alternative fuels. In general, the study shows that the different types of uncertainty are perceived by the actors as being a significant barrier that needs to be better conceptualised in diffusion theory.

1. Introduction

In the context of ongoing and forthcoming climate change, with potentially severe consequences for humans and ecosystems around the globe, a rapid reduction in the emission of greenhouse gases (GHGs) is essential. The transport sector is crucial and, in 2019, accounted for 24% of direct global CO2 emissions from fuel combustion (IEA, 2020). Freight transport constitutes an important and growing part of transport-related emissions and, at present, short-to medium-distance freight is heavily dominated by trucks that primarily run on fossil fuels. Many different measures are needed to reduce freight transport emissions, such as increasing vehicle efficiency, improving logistics and filling rates, as well as shifting to cleaner transport modes. The introduction of new fuels and technologies to substitute fossil fuels will be an essential part of the transition. Several alternatives exist and there will most likely be a need for a mix of fuels in future transport systems. This article focuses on the prospects of biogas as a new fuel in freight transport, in the Swedish context.

Biogas is a renewable biofuel produced from the anaerobic digestion of organic material such as household waste, manure or sewage water. In an upgraded form, biogas has the same propensities as natural gas and can therefore be used as a substitute for this fossil fuel. Compressed biogas (CBG) has existed on the market for some time, while liquid biogas (LBG) has only recently been introduced for heavy vehicles. Currently, biogas in transport is mainly used in buses and to some extent in private cars. However, thus far, in freight transport, there has been a slow diffusion although there are technologies on the market today.

Understanding how a new technology such as biogas can enter the market requires insight into the factors that determine the relevant actors' choices and decisions. The literature on the diffusion of green innovation aims to identify the enabling and disabling factors for the spread and adoption of new technologies (Mignon and Bergek, 2016; Clausen and Fichter, 2019). These factors may sometimes be divided into barriers and drivers and are diverse and associated with different levels of decision-making processes in both the production value chain and in society as a whole. The factors may be related to the market structure or 'the rules of the game', while other factors are closely linked with the innovation's function and purpose itself (Montalvo and Kemp,

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2008; Mignon and Bergek, 2016). Ideas and explanatory models from this literature will be used in this article as an analytical framework to better understand the case of biogas and freight transport.

The aim of this study is to explore the barriers and drivers regarding the use and diffusion of biogas as an alternative to diesel in the context of freight transport. The study focuses on the demand and user side of freight transport systems, seeking a deeper understanding of the challenges and motivations for actors such as transport buyers and haulage companies who are currently deciding what fuels to use for their transport needs. The empirical focus of the study is on the region of Västra Götaland in Sweden, and interviews with freight transport actors constitute the empirical material.

Prior research concerning biogas and transport has mainly focused on either the production side (biogas producers and distributors) or on passenger traffic and public transport (Cong et al., 2017; Fenton and Kanda, 2017). A few studies also focus on freight transport, although with different scopes, including production and demand side and shipping and road transport (Dahlgren et al., 2019; Takman et al., 2018). Previous studies have shown that unpredictable and volatile policies and regulations for fuels, as well as higher costs, are important barriers for investing and daring to try renewable alternatives (Ammenberg et al., 2018; Dahlgren et al., 2019). National policies on biofuels, electric vehicles and infrastructure also affect the tendency to choose biogas (Ammenberg et al., 2018). Uncertainty and knowledge gaps around biogas technology and its perceived potential as a fuel of the future are also barriers (Takman et al., 2018). The identified motivations for choosing biogas for freight transport are the environmental and circular benefits, political support and subsidies, as well as new vehicles compatible with LBG (Takman et al., 2018).

This article complements previous research on biogas and transport by focusing on the demand and user side of freight transport, and by using a theoretical framework on the diffusion of green innovation for the analysis. Existing studies on freight transport generally have no theoretical framework in their analysis. This article will therefore deepen the understanding of barriers and drivers regarding biogas for vehicle manufacturers, transport networks, haulage companies and their customers. Furthermore, prior studies have not to any great extent been able to focus on, or even include, liquified biogas, since LBG was just recently introduced on the market.

In the article a number of abbreviations are used and they are summarised in the table 1 below.

The outline of the article is as follows: Chapter 2 provides context by discussing biogas as a transport fuel and presenting the situation for biogas in Sweden today. Chapter 3 presents the analytical framework in which five categories of factors that influence the diffusion of green technology are identified. Chapter 4 describes the methodology with an introduction to the case study region. Chapter 5 presents the results of factors that influence the diffusion of biogas for freight transport. Chapter 6 provides a discussion on the prospects for biogas and the theoretical implications of the study. Finally, chapter 7 discusses the main conclusions of the study.

Table 1
Abbreviations.

Abbreviation	Meaning
CBG	Compressed biogas
GHG	Greenhouse gas
HVO	Hydrotreated vegetable oil
LCA	Life cycle analysis
LBG	Liquid biogas
RME	Rape oil methyl ester
TWh	Terrawatt hours
WTP	Willingness to pay

2. Biogas as a transport fuel

Biogas can be utilised in different ways, either directly in electricity and heat production or, if upgraded to biomethane, as a substitute to natural gas in the gas grid or as a vehicle fuel. In Europe, biogas is mainly used for electricity and heat production and only a small part is upgraded and used as a vehicle fuel. This is for example the case in two of the main biogas countries, Germany and Denmark. System studies have seeked to explore the best uses of biogas from an energy efficiency and economic point of view, and have reached different results. One study by Hakawati et al. (2017) shows that from an energy efficiency point of view, direct uses of biogas (electricity and heat generation) are preferred over transportation. In a Danish context Cong et al. (2017) come to the result that biogas can be favourably used in the transport sector from a both environmental and economic point of view. Korberg et al. (2020), on the other hand, argue that while biogas can be an alternative for commercial vehicles, it will compete with electric vehicles, and they conclude that biogas is best used directly for electricity or heat generation.

Sweden constitutes an exception in the European context since a majority of the available biogas is used in the transport sector. A possible reason for this is that electricity and heating in Sweden already uses a high share of non-fossil fuels while the transport sector is more of a challenge. In this paper we do not seek to answer the question what the best use of the biogas resource is but rather explore the conditions for biogas diffusion in freight transport in Sweden. In this chapter we will provide context to our analysis by reviewing the emission reduction potential of biogas as a vehicle fuel and describing the situation for biogas in Sweden today.

Previous research has shown that biogas as a vehicle fuel has the potential to reduce CO2 emissions by up to 100%, or even more, depending on the feedstock utilised, although the exact percentage of reduction varies across different studies (Lantz and Björnsson, 2016; Lantz et al., 2019). Börjesson et al. (2016) concluded that replacing gasoline or diesel with biogas from renewable sources lead to approximately 80% reduction of GHG in a well-to-tank perspective. However previous LCA:s concerning biogas made of organic waste, household waste and manure showed that a reduction of GHGs when replacing diesel may be as high as 103–148%, mainly because of saved emissions from avoided methane leakage caused by conventional manure storage (Börjesson et al., 2010). Additional benefits of biogas is that it can create a closed cycle for the treatment of organic waste while also providing a renewable fuel, contribute to increased energy security through domestic energy production, and stimulate rural development and businesses (Swe Gov Inquiry, 2019; Takman et al., 2018).

Biogas use in Sweden today is around 4 TWh of which around 2 TWh is domestically produced. More than two-thirds of the biogas is upgraded to biomethane and the main part is used as a vehicle fuel. Most of the biogas in transport is used in private cars or in buses. In Sweden, biofuels account for around 22% of all fuels used for road transport (Swedish Energy Agency, 2021). While most of this comes from biodiesel, biogas accounts for around 2%. In the bus sector the development has gone even further and in 2019 only about 10% of vehicle kilometres were run by fossil diesel or natural gas. Different forms of biodiesel are most common and accounted for 62% of vehicle kilometres. Biogas is however also widespread and accounted for 27% of vehicle kilometres in 2019, while electric buses still only constituted 1% (Svensk Kollektivtrafik, 2020). When it comes to freight transport the situation is different. Around 95% of the heavy trucks in Sweden are still diesel trucks, and out of newly registered trucks in 2019, around 5% were gas driven while only 1.8% were electric (Swedish Transport Administration, 2020; Transport Analysis, 2020). Approximately 90% of lighter trucks are diesel trucks (Swedish Environmental Protection Agency, 2020). Currently the use of biogas in trucks is low and although there has been some growth the use of biogas in trucks is still on a very small scale in comparison to the large use of diesel.

While domestic biogas production today is around 2 TWh, the potential is considerably higher. One study has calculated the potential to 15 TWh based only on residues from society and agriculture (Linné et al., 2008). According to a report from the Swedish Environmental Agency, there is a possibility that another 59 TWh could be produced from forest residues, making the total potential 74 TWh per year, which corresponds to about 90% of Sweden's energy supply needed for road transports (Swedish Environmental Protection Agency, 2012). Of the total energy used in road transports, approximately around 30% is used by freight traffic, according to calculations made by the Swedish Energy Agency in 2010 (Swedish Energy Agency, 2010). This means that in theory, the entire energy supply needed for freight transports by road in Sweden could be provided for using biogas only, if a bigger production of biogas is realised with the potential of feedstock residues from forest. While it is unlikely that biogas can be the sole technology that solves the fuel problems of the transport sector, it has the potential to play an important role in a transport system with a mix of sustainable fuels, combined with other measures to increase efficiency and reduce the need for transport.

3. Analytical framework

For the last two decades there has been increasing research on the diffusion of green innovation and technologies. Previous studies have aimed to determine and categorise the factors that inhibit or facilitate diffusion, and various analytical frameworks have been suggested for understanding the diffusion process (see eg. Montalvo and Kemp, 2008; Mignon & Bergek, 2016). The factors that determine or affect the diffusion of green innovation can be related to several different categories such as the innovation itself, market conditions, the industry or sector in which it is intended to be used, the regulatory and policy landscape, as well as the users' characteristics. Drawing on previous research we have identified five categories of factors that are particularly relevant to our biogas case. In the discussion we mainly refer to research conducted by Montalvo (2008), Montalvo and Kemp (2008) and Mignon and Bergek (2016). However, many of the factors are found in similar forms in other studies and we will also include references to the frameworks of other authors.

3.1. Technology and infrastructure

According to Mignon and Bergek (2016), a common barrier occurs when there is a lack of basic physical infrastructure or other resources essential for a functioning society, such as power grids, fuel stations, as well as knowledge or expertise in certain fields. The system is often dominated by a certain technology, creating a technical path dependency, resulting in a technical paradigm in the industry, from which is difficult and expensive to break free (Clausen and Fichter, 2019; Del Río González, 2005). An infrastructural challenge could also be if a gap exists between knowledge in research and knowledge in the industry in which a technology is meant to be used (Mignon and Bergek, 2016). Technical barriers can be linked to competence and resources, as well as supplier capacity (Mignon and Bergek, 2016). Montalvo and Kemp (2008) suggest that even with strong drivers from within the industry to try new, more environmentally sound alternatives, the diffusion of such alternatives may be too slow, or, in a worst-case scenario, not happen at all. The slow transition might sometimes be explained by the organisation's lack of capacity to renew, change and evolve (Del Río González, 2005; Montalvo, 2008).

A driver for diffusion could be the advantages associated with new technology. Rogers (2003) argues that the relative advantages, observability, compatibility, complexity and trialability are important factors that affect the diffusion and potential success of an innovation. User uncertainty and attitudes towards new technology may also be important factors, particularly if the innovation requires a change of behaviour (Clausen and Fichter, 2019). The perceived uncertainty and risk associated with replacing a conventional technology with a new technology appear to be an important barrier, and how big that risk is perceived is partially dependent on a company's ability to integrate new knowledge and its ability to handle organisational change (Montalvo and Kemp, 2008).

3.2. Market structure

Barriers related to market structure occur when the organisation and selection of the existing markets limit the possibilities for a new technology (Mignon and Bergek, 2016). The structure of the existing market might also affect the development of innovations in order for them to be compatible with the system. The impact on diffusion from the market is not merely negative, however. Increasing demand for a technology that offers, for example, lower emissions, from customers and consumers can be a strong driver (Montalvo and Kemp, 2008). Furthermore, shortages and rising prices regarding certain raw materials such as biomass in global markets sends signals to companies, and can thereby create a driver for companies to switch to alternatives which are easier to recycle or have a higher level of efficiency.

3.3. Economy and financing

Financial challenges are common barriers and are often caused by high investment costs when it comes to new technology. These costs, combined with risk and uncertainty in relation to volatile prices, may result in investors pulling out (Mignon and Bergek, 2016). A lack of financial resources, capital goods or opportunities for loans may also constitute financial barriers (Mignon and Bergek, 2016). Nevertheless, some green innovations may bring potential savings, for instance, lower energy consumption. Replacing a conventional dominating system means changing a technical path dependency and often results in significant costs. Because of this, it is important to take into account economic path dependency and price development when estimating diffusion (Montalvo and Kemp, 2008; Clausen and Fichter, 2019).

3.4. Policy and institutions

Institutional barriers comprise informal and formal rules such as laws, regulations, policy, norms and values that affect the selection of, and conditions for, new technology (Mignon and Bergek, 2016). According to Mignon and Bergek (2016), renewable energy innovations are often subject to unstable regulations. Montalvo and Kemp (2008) argue that regulations and policy instruments can also act as strong drivers for change, for instance, by imposing requirements on emissions. The importance of regulations and institutions as factors that influence the diffusion of innovations has also been highlighted by Fichter and Clausen (2016) and Kanda et al. (2016).

3.5. Attitudes and values

Although the influence of different stakeholders on the diffusion of green innovation is not completely clear, Montalvo and Kemp (2008) argue that civil society and external actors have a definite impact on the changed behaviours of consumers and act as 'watchdogs' of trade and industry by monitoring their ambitions regarding environmental and health issues. NGOs, green political parties and consumers have an important role to play in the adoption of greener alternatives, and higher demands from these stakeholders will help diffusion (Montalvo and Kemp, 2008). External pressure is not the only attitude-based factor. The values and motives of users overall appear to have an important impact on the possibility of diffusion (Mignon and Bergek, 2016). The attitudes of leaders and boards of companies might sometimes explain why a company chooses not to adopt a new technology, even when other drivers are present, such as consumer demand (Montalvo and Kemp, 2008).

4. Methodology

The method used for this study is a qualitative case study in the region of Västra Götaland in southern Sweden. The motivation to choose a qualitative case study design was that we have been interested in exploring how the involved actors themselves perceive the challenges and opportunities of biogas and their reasoning when deciding which transport fuel to use. The intention has been to conduct a contextually grounded analysis rather than to achieve statistically generalisable results. The region of Västra Götaland has been chosen since it has good conditions for biogas and is also an important region for freight transport in Sweden. It is a highly populated metropolitan region with a lot of industrial and trade activities. There are 49 municipalities in the region, including Gothenburg, which is Sweden's second largest city. The port of Gothenburg is the largest in Scandinavia and therefore generates a high volume of freight transport. In theory, biogas should have a good basis in Västra Götaland, with several existing biogas production plants, the presence of a vehicle manufacturer, two universities and municipalities with systems for collecting organic household waste. Thus, the conditions and opportunities for biogas can be assumed to be similar or better than other regions both in Sweden and internationally.

The empirical material for the study comes from 13 interviews with respondents representing actors in the freight transport market in the region (see Table 2 for information about the interviews). The focus of this study has been on the demand side of transport, that is, the actors who will potentially use biogas for freight transport. The motivation for this focus is that both freight transport and the demand side have been neglected in previous research on biogas as a transport fuel. Four types of actors have been included in the study: transport and haulage companies, transport purchasers, vehicle manufacturers and a biogas network organisation. The selection has been made in dialogue with experts on freight transport at the environmental research institute IVL. General criteria were to select actors who have shown an interest in renewable fuels, or who have a clear sustainability profile, in order to gain an overview of the challenges facing actors who are committed to change. Below is a brief description of the four types of actors.

Table 2
List of interviews.

Organisation	Respondent's title	Date of interview	Type of actor
DB Schenker	Head of CDS & Sustainability	23 March 2020	Transport & Haulage companies
DHL	Business Process Management, Sustainability Department	13 March 2020	
Postnord	Environmental Specialist	17 March 2020	
Götene Kyltransporter (GKT)	CEO	20 March 2020	
LBC Borås	Business Area Manager, Goods and Logistics	24 March 2020	
GB Framåt	General Manager	26 March 2020	
Estrella	Head of Environment & Energy	19 March 2020	Transport Purchasers
Jula	Sustainability Manager	1 April 2020	
Doggy	Purchasing Manager	25 March 2020	
Cementa	Strategic Purchaser, Logistics	3 April 2020	
Volvo Trucks	Director Environment and Innovation	11 March 2020	Vehicle Manufacturers
Scania	Senior Advisor Sustainable Transport	1 April 2020	
Biogas Väst	Process Manager	18 March 2020	Biogas network organisation

Transport and haulage companies are key actors in the field of freight transport as they are responsible for procuring, owning, refueling and managing trucks, operating the transport and communicating with their clients in order to meet their requests. Six companies were interviewed in this category: three large transport companies working with smaller haulage contractors throughout Sweden (this region included) and three other transport companies, two of which are regular haulage companies, and one local transport network, which is owned by its haulage contractors. *Transport purchasers* are clients of the transport and haulage companies. They are relevant since they can affect the demand for renewable fuels and they often have closer contact with consumers and their demands. Four companies from different parts of the region who regularly buy transport services from external actors were selected for the interviews. *Vehicle manufacturers* are also important actors regarding the kinds of fuel that are selectable and relevant as they develop the vehicles that are available on the market. Two large truck companies with a significant market share in Sweden were interviewed. We also interviewed a publicly owned *biogas network organisation* aimed at supporting the use of biogas in the region. The reason for this was to add a comprehensive holistic view of the barriers and drivers for biogas.

The interviews were informative which, in this case, means that the respondents acted as representatives of their organisations and were interviewed because they were knowledgeable about their organisations, the decisions made and the topic of transport, biogas and sustainability. The respondents worked with innovation, transport and logistics or sustainability and the environment. In some of the smaller organisations, the respondents had higher management roles with a good overview of business decisions regarding the environment and fuels. The interviews lasted between 40 and 90 min. All interviews except two were recorded and transcribed in full. Of the two interviews that were not recorded, one respondent answered questions via email and another asked not to be recorded and notes were taken instead.

A similar interview guide was used for all interviews though slightly modified to fit the type of organisation being interviewed. The questions were organised around three major themes. The first theme included questions about the company's sustainability strategy regarding freight transport and fuel choice. The second theme focused on biogas, including questions about whether the organisation had considered biogas, pros and cons, opportunities and obstacles with the fuel compared to other alternatives, and whether it intended to use biogas in its future operations. The last part of the interview revolved around the impact of political decisions on the choices of the organisation and views on policy instruments regarding renewable fuels and biogas. The questions were formulated to be as open as possible in order to create a semi-structured interview environment and to avoid influencing the respondents' answer.

The analysis was conducted using the analytical framework previously discussed in this paper. The respondents' answers were analysed and coded using Nvivo, following the identified categories of barriers and drivers: technology and infrastructure, market, economy and financing, policy and institutions, and attitudes and values. The answers under each category were then related to descriptions of a corresponding or relevant driver or barrier in the analytical framework and literature.

The study targets road transport by truck, meaning that sea transport, rail freight and aircraft were excluded. Also, passenger transport is not a focus of this research. Furthermore, the research is conducted in a Swedish context, specifically focused on the region of Västra Götaland, although a majority of the companies included also engage in activities and transport in other parts of Sweden. The qualitative research approach generates results that cannot be empirically generalised. However, the results do allow for analytical generalisations to be made for similar contexts in both Sweden and elsewhere.

5. Results

This chapter presents the analysis of the factors affecting the diffusion of biogas in freight transport, as experienced by the respondents in our study. The analysis is structured according to the five categories of factors identified in the analytical framework. In the analysis, both barriers and drivers are discussed. Since we interviewed respondents from different types of organisations, we present both the main results from the interviews and more differentiated responses when this is of relevance.

The overall result is that the respondents from all the categories were mainly positive about biogas as a fuel, and many of them believe that the adoption of biogas for transport will increase. They also expressed a willingness to commit to a transition to a more sustainable transport system. However, most of the respondents stated that the conditions had to be right, certain types of support and measures needed to be in place, and some obstacles overcome, in order for an increase in the use of biogas to take place. Furthermore, many respondents expressed concerns that the transition to renewable fuels is too slow, and some of the barriers tend to slow down the desired development.

5.1. Technology and infrastructure

Technology and infrastructure came across as a very important category according to the interviews. A significant barrier highlighted by many of the respondents is the fact that biogas requires a so-called dedicated support technology, which means specific types of engines, a specific infrastructure for gas, and various kinds of expertise regarding service and operations. Several respondents brought up the problem that there is a lack of infrastructure and accessibility of biogas, particularly concerning liquid biogas (LBG). The respondents from DHL and LBC Borås argued that it is not just an issue of the number of gas stations, but that they need to be in the right location in relation to transport activities. Detours to re-fuel with biogas instead of diesel cost money and time for which neither haulage contractors nor clients are capable or willing to pay.

"You can't drive 40 km just to re-fuel. Those fuels that require this will be omitted. No customer will accept you driving 40 km extra on their behalf. They expect us to use the normal route." (Interview with LBC Borås).

An insufficient number of gas stations may also result in queuing, which is costly for both driver and vehicle. Volvo Trucks, Cementa and Postnord describe the whole situation as a kind of Catch 22, in which gas companies won't venture to build gas stations when they can't be sure that there are enough trucks, and, in turn, the transport companies won't buy trucks until there are enough gas stations. However, it should be noted that with regard to compressed biogas (CBG), the infrastructure is more established. It should also be noted that while almost all respondents pointed to the problem of an absence of infrastructure, many respondents also stated that the number of gas stations (particularly for LBG) are increasing, and that the situation in the region is probably as good or even better than other regions in Sweden.

According to several respondents, another barrier associated with biogas technology are the benefits of other alternative fuels. The main benefit of biodiesel, such as HVO, is that it can be used in existing diesel engines which means that it does not need new infrastructure. The advantage of the electric vehicles, on the other hand, is that it has zero end-pipe emissions, higher efficiency and silent running. As batteries and electric trucks become more accessible and an attractive alternative in the eyes of many actors, this might impede the use of biogas, since these actors might put resources and effort into preparing for an all-electric fleet.

Nevertheless, according to all the respondents, biogas also has many benefits, from an environmental and sustainability perspective, regarding production, carbon emissions, circularity, access and materials, particularly in comparison to HVO. The fact that biogas is more established than electric vehicles and uses no batteries (and thus has better range per refueling which is suitable for longer transports) is also considered an advantage, according to GB Framåt, Cementa and GKT. According to several respondents, the compatibility of biogas with a circular society and production systems might be one of the most significant advantages.

5.2. Market structure

From the interviews it appears that the structure of the freight market is an important factor to take into consideration. According to Volvo Trucks, Biogas Väst and DHL, a high proportion of the market comprises small haulage contractors, sometimes with only a few trucks which, in turn, are often procured by transport networks. Small companies are more vulnerable to costs and risks in investments. Furthermore, the respondents from DB Schenker, DHL, GKT, GB Framåt and Volvo Trucks described the sector as being characterised by small margins and small profits. A mistaken investment in a vehicle might therefore heavily impact a transport company and cause actors to be even more careful and hesitant about trying out new fuels.

"There are rather small margins and low profitability, which makes it difficult for our customers who, in many cases, are very small companies, including many single drivers, to be able to invest in an expensive technology when there is also uncertainty about what might happen in the future." (Interview with Volvo Trucks).

The existing market structure acting as a lock-in and barrier is even clearer when you take into account that a fossil-free transport system probably requires several renewable fuels, rather than only one that dominates the whole market. In addition, some respondents (GKT, Volvo Trucks) argue that the freight and transport industry is generally conservative, showing a resistance towards change and trying out new ideas. According to DHL, a market-related driver is the fact that biogas has been established on the market for a while now, which provides a sense of security and a good reputation. Postnord, Scania, GKT and Cementa describe biogas as a stable, commercially-accessible and relatively competitive option. At a time when the supply of and market for other imported biofuels such as HVO is uncertain, the supply of raw material for biogas, produced domestically, is regarded as more secure by some actors. According to Scania and Volvo Trucks, a growing interest in both natural gas and biogas in Europe is also a potential driver, since European support for gas favours the development of biogas in Sweden.

5.3. Economy and financing

According to all the respondents, a transition from diesel to biogas results in increased costs in different ways. Higher initial investment costs (compared to an equivalent diesel vehicle), lower trade-in value, higher costs for service and maintenance and volatile fuel prices in combination represent a strong barrier to investing in biogas and reinforces the perceived uncertainty and risk.

The price of fuel was discussed by all transport actors and vehicle manufacturers and some of them thought that the price was acceptable while others considered it too high. A problem regarding the price of biogas appears to be the volatility of oil prices, as stated by Biogas Väst. When oil prices occasionally plunge, biogas cannot compete, particularly in a sector with low margins and pressured prices in which every possible type of saving needs to be made. Many of the respondents argued that because of this, tax subsidies are crucial for biogas competitiveness.

According to the respondents from the transport side, another problem related to increased costs is the clients' low willingness to pay (WTP) for green transport. To be able to buy and operate gas trucks, it is necessary to have a client who is willing and capable of sharing the costs. According to the respondents from the haulage companies, such clients are too few in number. However, many of the respondents, including DB

Schenker and Scania, also stated that they are beginning to notice a slow rise in WTP. The respondents representing clients of transport companies generally stated that they are sometimes willing to pay extra for more sustainable transport. However, there are limits to how much extra this can be. For example, Cementa stated that its products have low margins, which means that the transport cannot be too expensive otherwise it will not break even. Estrella added that the cost must always be weighed against the environmental benefits and reduced emissions. The respondent from Doggy stated that, as of now, they pay extra for biogas, but that their ability to pay more is, in turn, limited by their customers' WTP.

According to several of the respondents from transport and haulage companies, transport is in general not valued highly enough, which is a significant barrier. DHL stated that transport is not typically discussed in board meetings or by higher management. GKT, DHL, DB Schenker and GB Framåt also said that there is a norm stating that transport services should be inexpensive and that this norm exacerbates the problem with low WTP. Because the price of shipping is often embedded in the total price in the e-commerce industry (purchase for a certain amount and get free shipping), there is an illusion of transport being basically free, according to the respondent from DB Schenker. This respondent also problematised the fact that transport is so inexpensive, considering its value and necessity from a social perspective.

"Today, in general, I would say that transport is too cheap, if you look at how small a proportion the transport price is compared to the end value of a product. And, of course, there is no such thing as free transport. It costs." (Interview with DB Schenker).

5.4. Policy and institutions

All respondents stated that regulations, policy instruments and politics have a major impact on their operations and the ability to transition to renewable fuels. One of the most emphasised barriers from many actors is the lack of long-term decisions and planning from political actors. DHL, GKT, DB Schenker, Postnord, Volvo Trucks and Scania all pointed to the difficulty of daring to invest in biogas vehicles or other renewable alternatives and the associated technology when subsidies and other economic support could be removed or changed only a short while after it had been put in place. This frustration is evident in the following quotation from one of the transport companies.

"It's the Swedish government, it's always been like this, they can be very indecisive. It doesn't matter what we buy, it will still be wrong. We have to start again and run in this direction, then the taxation changes again and we have to run in that direction. There is simply no straight line. It's a real concern!" (Interview Götene Kyltransporter).

Furthermore, experiencing failure for other renewable fuels in the past (such as RME and ethanol), partly because of political changes, causes actors to be even more wary of making the wrong investment decisions. In relation to the uncertain policy landscape around renewable fuels, some actors still view diesel as the safest and most comfortable choice.

Even though several respondents asked for more long-sightedness, a majority also saw strong drivers associated with policy around biogas. Vehicle manufacturers and transport companies in particular point to the importance of general political support, tax subsidies and other financial support in Sweden.

It is not only national regulation and policy that affect the actors' decision-making regarding fuels. Cementa, GB Framåt and LBG Borås all point to the impact of cities implementing more stringent requirements for emissions from heavy vehicles and traffic, both in Sweden and adjacent countries. For example, the respondent from Cementa stated that the city of Oslo has decided on fossil-free construction sites which, in turn, act as a strong driver for changing Cementas' transport from the region of Västra Götaland region all the way to Norway, where biogas is a possible option. Other respondents such as Scania also suggest that environmental zones in cities in both Sweden and Europe generally favour the increased use of both biogas and electric trucks. Estrella added that permits and monitoring from local authorities sometimes also constitute drivers for change. Another positive influence that supports the increased use of biogas and other renewable fuels may come from long-term strategies and directives from the EU, showing a will and desire for change, as described by Volvo Trucks.

5.5. Attitudes and values

The respondents stated that values and attitudes can be important drivers in the conversion from diesel to renewable fuels. Most respondents from all categories stated that their sustainability ambitions are important to their organisations and crucial to their brand. Many of the respondents emphasised the serious commitment of their company, and that they have observed similar sustainability ambitions with other actors in their network. Scania, Volvo Trucks, DB Schenker and DHL all suggested that sustainability is very important, not only in itself but because it is essentially a question of a company's survival in the market. Sustainability and climate change are becoming so central that companies must make a serious commitment, not only to stay relevant to their customers, but also to be able to attract talent and be a relevant employer.

According to several respondents, a growing debate around sustainability and pressure from consumers, NGOs and citizens in general is a major reason for the commitment to sustainability of their company and clients and, by extension, a motivation for choosing renewable fuels such as biogas. The respondents from Postnord, Cementa, Volvo Trucks and Estrella stated that they had noticed a higher demand and growing interest in sustainability from their clients, including specifically for transport services.

Although the respondents stated the importance of sustainability values both in their companies and in society at large, the connection to changes towards adopting alternative transport fuels is less clear to make. As we saw above transport in general is not valued very high and the willingness to pay extra for greener transport is still limited. Eg. the respondents from the transport purchasers generally highlighted the fact that transport is important but stated that they had other environmental issues they had to deal with in their organisations. Cementa and Estrella indicated that while they are interested in becoming better regarding the environmental impact of freight transport, they did not necessarily see it as their job to lead the transition towards a fossil-free vehicle fleet, and that it is important that transport companies lead the way as they are the experts. Also, in this context it is important to keep in mind that these are barriers and drivers as perceived by the respondents, and thus not necessarily objective truths. Even if many actors on the commercial market claim that sustainability is growing in importance, it still seems to a big extent as if the price tags lead the way in decision making.

6. Analysis and discussion

In this study we have analysed the conditions for diffusion of one renewable fuel, biogas, in one particular context, freight transport in Sweden. We have done this mainly from the point of view of users, that is, freight transport companies and those companies using freight services. The analysis has been conducted based on an analytical framework on common factors affecting the diffusion of new technologies, which has allowed us to discover both what is particular about this case and in what way the framework manages to capture the user perspective, or if there is a need for theoretical development. We will thus divide the analysis and discussion in two parts. First, we will discuss the prospects for biogas diffusion in freight transport based on the views of our respondents. Second, we will reflect on the theoretical learnings of the case and further development of the framework.

6.1. Prospects for biogas

Biogas is a renewable fuel with benefits both regarding GHG emission reductions and its contribution to the recycling of organic waste. It will most probably have a role in future waste and energy systems. While it can be used as a transport fuel there are also other uses and the current use differs between countries. In Sweden, biogas has been promoted as a transport fuel both in private cars and in buses, but less so in freight transport up to now. All respondents in the study (freight companies, customer companies, vehicle manufacturers) see biogas as a potential fuel for freight transport and recognize its positive attributes. LBG seems to have more advantages and better prospects than CBG, from the perspectives of our respondents, and seems to be favourable for long distance transport. For shorter routes with lighter lorries, for example in cities, electric vehicles may be more suitable and may have a competitive advantage. However, they also see several problems and hurdles which make it uncertain whether biogas will become a major fuel in freight transport or if it will be used in other contexts. Biogas needs to compete with the existing diesel dominated freight transport as well as other new technologies, mainly electric vehicles. The main barriers for biogas from the perspective of the respondents are costs and lack of infrastructure. These are common barriers according to diffusion theory but they play out in particular ways in this case.

Increasing costs are an issue for several reasons, in both initial investments in trucks, as well as in terms of service, lower resale value, volatile gas prices, and detours because of the low number of gas stations. Costs in combination with a low WTP and tight cost margins were emphasised as being a major problem by all the haulage companies and transport networks. High costs are found to be a barrier in previous research, while the specific challenges of the freight sector in regard to small actors, tight margins and low profit, has been less acknowledged.

In our results, a lack of infrastructure is also shown to be a fundamental issue for the increased use of biogas, particularly regarding liquid biogas (LBG). An insufficient number of gas stations in the right locations close to the actors' routes appears to be a dealbreaker for biogas. LBG requires a separate infrastructure that is quite new and has not been established yet, unlike biodiesel such as HVO, which can be used in the existing diesel infrastructure. We argue that these problems can be seen as a symptom of a technical path dependency, created by the, until now, complete dominance of diesel for the truck segment of the transport system. This is in line with Montalvo and Kemp (2008), who suggest that such a lock-in state can be very difficult and expensive to change.

To the favour of biogas is that it is fairly well established as a vehicle fuel in Sweden, that the benefits are well recognized, that it also has local benefits and that there is a policy setting in Sweden supporting biofuel development. The prospects for biogas seem to depend a lot on how the fuel market for freight transport will look in the future. One possibility is that we move into a more mixed system with several fuels and technologies existing side by side. Another scenario is that the sole dominance of diesel will be replaced by another single technology. It is unlikely that biogas will become the only dominant fuel, since it is probably too big a challenge to realise the production supply needed to cover the growing fuel need from the transport sector. However biogas can play a significant role in a more mixed system and there is potential to expand the production a great deal more than today. But this also depends on what direction is decided for other possible use areas, such as shipping or industry, and how the demand for biogas is formed.

A comparison to the bus sector in Sweden can shed light on both the possibilities and differences. As previously explained, the bus sector in Sweden is almost fully run on renewable fuels and biogas accounted for 27% of vehicle kilometres in 2019 (Svensk Kollektivtrafik, 2020). Bus traffic is publicly financed and there has been a political push to phase out diesel as a fuel. In some regions biogas has become a significant option often due to regional concerns such as the will to support local biogas production (Aldenius, 2018; Aldenius and Khan, 2017). Compared to the freight transport market, the regional public transport authorities are both larger in size and politically steered which has made it possible to invest in biogas vehicles, with the extra costs implied and need to build the necessary infrastructure.

6.2. Theoretical implications

In general, the findings of our paper are in line with previous research and the theoretical framework was helpful to understand the empirical case. Some observations are of interest for further theoretical development. First, our focus on the user side has led to a more nuanced understanding of the characteristics of the freight transport market, which is of importance to understand the diffusion of new technologies. Many of the transport haulers are very small companies with tight cost margins which limits their capacity and will to invest in new technologies. Again a comparison to the bus market in Sweden is in place. Although respondents from customer companies put the responsibility on freight companies these are less likely to be able to act without strong support to make the necessary investments. This study emphasizes the importance of paying close attention to the structure of the market and the conditions of the users of the new technology. The theoretical framework used in this study does not in a satisfying way provide a tool for describing and understanding the characteristics of the market and how strongly they may affect diffusion. However the importance of market formation in different contexts is investigated and discussed in studies on the introduction of technical innovation systems, for example in the case of solar power in Germany (Dewald and Truffer, 2011, 2012).

Another general finding is that interaction between factors is what really matters. Although, costs and infrastructure came out as important factors it is really the specific configuration of factors that matters. In our case this was the most obvious regarding the role of uncertainty. Our results show that the cumulative uncertainty faced by many actors when choosing a renewable fuel instead of diesel is a major problem. The respondents stated that this uncertainty manifests itself in many ways, such as knowing which technology will be most suitable and established in the next decade, knowing whether there is a sufficient supply of the fuel, whether political support will still be in place and what fuel customers will prefer. Furthermore, the sense of uncertainty when investing in renewables appears to be reinforced by the memory of what is perceived as the failures of renewable fuels in the past, such as RME and ethanol. Some of these uncertainties are described in previous research as a problem for biogas (see e.g. Ammenberg et al., 2018; Dahlgren et al., 2019).

We argue that uncertainty as a barrier is not sufficiently described in the theoretical literature on the diffusion of green innovation. This is noteworthy considering the emphasis that so many respondents place on this problem, not just from transport companies but also transport purchasers and vehicle manufacturers. It is also interesting to try to establish connections between uncertainty interactions between barriers on one hand, and certain types of markets or sectors on the other, for example the difference in uncertainty when comparing public transportation and freight transportation. Uncertainty is a vague concept that can be hard to pinpoint in a theoretical way. Yet it appears to be an important ingredient when transport market actors make their decisions and strategies regarding if and when to invest in renewable fuels. The development of theoretical models that include a better understanding of the role of uncertainty might be a way of improving the framework and further explaining if, when and how the diffusion of green innovation, and specifically renewable fuels, will happen.

In this study we have looked at one fuel, biogas, and asked respondents about how they view its prospects. In future studies it would be interesting to study several fuels and technologies at the same time in a comparative design. One finding of the study is that a new technology has to compete both with the existing dominating technology and relate to other emerging alternatives. Such a combined study would allow for deeper knowledge on how emerging technologies interact and either

compete or complement each other in the diffusion process.

7. Conclusions

In this paper we have studied the diffusion prospects of biogas from a user perspective regarding freight transport in Sweden. Our results show that the respondents generally view biogas as a promising fuel option, and the main drivers include an increasing demand for sustainable products and transport from both society and end consumers, a strong perception of environmental and other benefits of biogas (e.g. that it is consistent with a more circular society and benefits a domestic energy supply), and the existence of a general policy framework that supports biofuels. We also found that respondents were particularly positive to LBG which is interesting since it is just recently introduced to the market, but still seemed to be the most relevant form of biogas for the majority of our respondents. LBG is different from CBG regarding a few important parameters such as range, and thus we argue that conclusions drawn about the diffusion of CBG may not always be true for LBG.

Still, our study also found important barriers to biogas in freight transport as it competes both with existing diesel fuel and other emerging renewable technologies. Multiple costs and low WTP from customers, lack of infrastructure, uncertainty about choosing the right renewable fuel and specific market conditions seem to be the biggest obstacles for biogas. Furthermore, our results suggest that it is the mix of barriers which, in combination, have the most crucial impact on the use of biogas for freight transport. Although some factors appear to be more important, it is the mix and interaction that makes the situation complex and difficult to address from a policy perspective. The most clear example may be the combination of unfavorable market conditions for freight transport, several costs and competing renewable fuel technologies for lorries, which together creates uncertainty and a perceived risk for freight transport actors. One particular challenge is the fragmented market structure comprising a mix of large and very small transport companies, in which profit margins are tight and the capacity for investment and taking economic risks is small. There is also a division of labour and responsibilities between transport companies and transport buyers, which makes it unclear who will be the driver in a transition to alternative fuels.

If there is a wish to introduce biogas to freight transport, policymakers need to take into account the specificities of the freight transport system and the particular needs of market actors when designing policies to support the increased diffusion of biogas in this context. One implication is that support is necessary in all stages of the value chain, including the production of biogas, investments in infrastructure and vehicles, and the use of biogas in freight transport. Another finding is that, since transport costs are generally undervalued, it is desirable to find ways of preparing consumers to pay what it costs to make freight transport less polluting.

While actors who want to use biogas for road transports may overcome some of the barriers underlined in this study if the infrastructure is in place, we argue that it is important to remember that all parts of society must eventually run on renewable energy and thus are in need of renewable fuels. Biogas production and use will most likely increase both in Sweden and elsewhere but it is an open question in which areas and sectors it will be used. We conclude that biogas can have a role to play in transport in general, and freight transport in particular, if the sector will comprise a mix of fuels in the future and if the current barriers are addressed in an appropriate way.

CRediT authorship contribution statement

Hanna Björner Brauer: Conceptualisation, Methodology, Interviews, Transcription, Formal analysis, Writing – original draft. **Jamil Khan:** Formal analysis, Writing – original draft, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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