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Drivers for and barriers to biogas use in manufacturing, road transport and shipping: a demand-side perspective

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ABSTRACT

Contemporary environmental problems require a transition to renewable energy. Biogas is one alternative, which besides being renewable has many other benefits. For further expansion of biogas production, it seems necessary to develop new areas of biogas usage where biogas can replace fossil fuels. This article presents an analysis of the drivers for and barriers to increased biogas usage in three sectors where biogas usage is undeveloped in Sweden: manufacturing, road transport and shipping. Several of the identified drivers and barriers, such as unstable and short-term policies, lack of infrastructure, and contract requirements, have also been found in previous studies even though they may be slightly different depending on the context. A new driver observed in this study is that of intergenerational thinking in family-owned businesses. The study also reiterates the significant influence of policy in the form of subsidies, tax exemptions and regulations on the adoption and use of renewable energy in general and biogas specifically. The results suggest the need for future policymaking to be guided by long-term trajectories, which can be a relevant basis for adopters to make investments into biogas technologies.

Introduction

Most countries in Europe have in recent years launched strategies to replace fossil fuels with more sustainable alternatives [1]. Despite some advancements in the transition to renewable energy, many countries are still far from reaching the targets set in the EU climate and energy package [2,3]. In Sweden, 54% of the gross energy consumption is covered by renewable fuels, which is the highest share among the EU member countries [3]. However, 100 TWh of the total energy consumption of 117 TWh in the transport sector still came from fossil fuels in 2016, and the manufacturing industry used 26 TWh of fossil energy [4]. To achieve the ambitious goal set by the Swedish government – that the country will be fossil-free by 2045 – fossil fuels need to be substituted in both the transport and manufacturing industry sectors. Presumably, many different biofuels will be needed for this transition [5], but the roles of the alternative fuels in the future energy system are not self-evident.

Biogas, methane produced from anaerobic digestion of biomass, is one of the fuels that can contribute to this transition. Biogas can be produced from many different sources: crops, crop residues, manure, industrial organic waste, wastewater, and organic wastes from, for example, food and forest industry. Apart from offering renewable energy, the production process often has other benefits such as reducing the amounts of sewage sludge [e.g. 6,7], increasing nutrient recirculation [e.g. 8,9], and reducing methane spills from manure [e.g. 10,11]. In Sweden, 2 TWh of biogas was produced in 2016. However, according to the ‘Proposition for a national biogas strategy’ [12], there is potential to expand production to 15 TWh by 2030. A difficulty is, however, that many factors influence this theoretical potential [13]. The municipal waste sector has up to now dominated biogas production in Sweden [14]. Currently, most of the produced biogas is upgraded to vehicle gas, which today is one of the most important fuels for city buses [15]. However, the competition has increased due to the introduction of electric vehicles and expanded use of biodiesels [16]. For further expansion of the market for biogas, it therefore seems necessary to develop new areas of biogas usage where biogas can replace fossil fuels.

Industrial gas users, road transport, and shipping have been suggested as potentially important biogas users in the future [12,17]. This study addresses the prospects for expanding biogas usage in these three sectors that up to now have been marginal usage areas in Sweden. Our goal is to contribute to the current discourse on increasing the share of energy from renewable energy sources in different sectors. To do so, we address the following research questions: (i) what are the major drivers and barriers for increased biogas usage in the road transport, manufacturing sectors and shipping? and (ii) in which settings can biogas already be a feasible option and what is needed for wider introduction and use in other settings? By addressing these questions, we contribute to the identification and understanding of drivers and barriers for expanding biogas usage into new, or up to now rather marginal, usage areas. In relation to the most recent studies [e.g. 1,15,16] that focus mainly on the potential use of biogas for transportation in cities, this study contributes by analyzing sectors with large potentials for increasing biogas use, which have not been covered by previous studies.

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This article is structured as follows: in the next section, we present a brief overview of how biogas is used today in Sweden and the three potential usage areas studied. The third section presents the approach used in the research. In the fourth section, we present a framework to analyze the drivers for and barriers to adoption of biogas as an energy carrier. In the fifth section, we present the results, followed by a discussion in the sixth section. Conclusions and policy recommendations are highlighted in the seventh section.

Biogas use in Sweden

Biogas production was first introduced in Sweden with the development of wastewater treatment in the 1960s, with the primary aim of decreasing sewage sludge amounts [18]. In the 1970s and 1980s, some production was started in agriculture and in the forest industry, and landfill gas collection was introduced at major waste deposits [19]. Until the mid-1990s, the produced gas was almost only used for covering local heat needs, but since then, the most important usage has become as vehicle gas (Figure 1).

In comparison with most other European countries, electricity consumption in Sweden is high, while gas use is low, particularly in the household sector [3]. Almost all electricity production comes from nuclear power, hydro power and other renewable sources, and most of the heat needs are covered by biomass. Therefore, the transport sector is responsible for about half of the greenhouse emissions and has been the dominant focus of climate change mitigation, and biogas has primarily been viewed as a fossil-free vehicle fuel alternative. Between 2005 and 2015, the upgrading of biogas to biomethane increased 11-fold [20]. In 2017, 63% of the produced biogas was upgraded in Sweden, which was the largest share of biogas production used for transport in Europe [20].

However, the sales of new gas vehicles in Sweden have stagnated since 2014 [21]. Other renewable fuels such as hydrogenated vegetable oil (HVO) and rapeseed oil methyl ester (RME), which can be used in diesel vehicles, have gained importance in the public bus sector, and plans for introducing electric buses have been developed [16]. The growing production of upgraded biogas fuel is increasing the share of biogas in the gas grids [22] which, however, only cover a small part of the country. In regions without gas grids, there have been tendencies of overproduction, and investments in new production have stagnated since interregional freight of biogas is not economically attractive. This has stimulated an interest in looking for alternative usage areas.

Potential new usage areas

Three areas where the use of biogas is not widespread, but where it could replace the current use of fossil fuels, are manufacturing, road transport and shipping.

Manufacturing

The manufacturing sector is, after transportation, the second largest fossil-fuel-using sector in Sweden, with a yearly use of over 26 TWh – approximately 20% of the total energy use in the industrial sector [4]. Of this, about 8 TWh is natural gas and 4 TWh is liquefied petroleum gas (LPG) [4]. Natural gas is interchangeable with upgraded biogas, and industries using natural gas would thus not face any added costs in changing their facilities to biogas use. In the last couple of years, some industries have switched from either natural gas or LPG to biogas [e.g. 23–25]. One reason for this is the gradual abolishment/phasing out of tax exemptions for natural gas and LPG in manufacturing companies [26]. To enable the use of LPG that has slightly different properties, some adaptation of processes is (most often) required. The size of industries and their fossil fuel use varies – some use much less than 1 GWh of fossil gas yearly while others use greater amounts annually than Sweden’s largest biogas production plants produce (i.e. 120 GWh).

Road transport

The transport sector is the largest fossil-fuel-using sector in Sweden, with a yearly use of 100 TWh (including international bunkering) [4]. In 2014, 17% of the sectoral greenhouse emissions were related to heavy transports and buses [27]. Diesel is the most common fuel for lorries in the world, and 97% of the heavy lorries were diesel lorries in Sweden in 2016 [21]. Recently, some large auto producers have started to produce heavy road vehicles using liquefied natural gas (LNG). In 2017, there were around 100 refueling stations for LNG in Europe [28] but one company is building more than 50 refueling stations in Scandinavia by 2020 [29]. The technology used for methane gas lorries is not compatible with diesel, and investments in new vehicles and refueling infrastructure is required for a switch to biogas. In contrast to manufacturing, road transport
consists of many small moving units that need to be able to refuel in different places. Some lorries are used for longer distances and heavier cargo, while others are used for shorter distances more locally and in central areas. The tax exemptions in Sweden for renewable fuels such as biogas are of central importance for motivating biogas substitution in road transport.

**Shipping**

In 2014, 25% of greenhouse gas emissions from the transport sector were related to national shipping and international bunkering of shipping fuel [4,27]. The shipping fuels bunkered in Sweden are primarily related to international shipping. It is difficult to develop policies for increasing the share of renewable fuels and taxing fossil fuel. Some emission regulations have been introduced, but those policies concern sulfur, nitrogen oxides and particles rather than greenhouse gases and renewable fuels. However, they create incentives to choose LNG in new ships, and LNG ships have begun to diffuse in the last few years. In 2017, more LNG ships were built than were already in use [28], and half of the ships that were built for Swedish shipping companies were prepared for LNG [30]. The shipping industry is quite diverse – some ships traffic the same ports all the time while others navigate numerous ports, and some are used for long distances and more cargo while some ferries only go short distances before turning back again.

**Research approach**

This study has approached the barriers to and drivers for biogas usage in road transport, manufacturing and shipping based on insights from previous scientific studies that addressed the adoption of renewable energy technologies in general, and on interviews with selected companies.

The analysis is particularly inspired by the works of Ingrid Mignon and Anna Bergek [2,31]. We selected their works as a starting point for three main reasons. First, their contributions are based on an integration of different strands of literature relevant for the analysis of the diffusion of renewable energy technologies. These strands of literature are: (i) diffusion modeling approaches [e.g. 32] which seek to describe and explain the overall diffusion patterns of technologies; (ii) socio-technical systems approaches [e.g. 33] which analyze at the system level the underlying processes of innovation and diffusion in different institutional contexts; and (iii) the diffusion of innovation literature [e.g. 34] which emphasizes the characteristics of the individual adopters in technology diffusion. Second, Mignon and Bergek [31] acknowledged that the diffusion of renewable energy technologies is not only dependent on an isolated adopter decision, but also a collective activity influenced by an aggregate of factors related to the institutional context. Third, their contributions [2] cut across the heterogeneity of renewable energy technologies and adopters in different institutional contexts.

Additional strands of literature on the diffusion of environmental technologies [e.g. 35,36] and biogas solutions [e.g. 1,37,38] played a complementary role. The literature on diffusion of environmental technology emphasizes technology characteristics (i.e. the potential environmental benefits and the influence of policy as particularly important in diffusion), while the literature on the diffusion of biogas solutions highlights drivers and barriers that are specific to biogas as an energy carrier. The empirical findings of our study are summarized as a framework of drivers and barriers on both system and actor levels (in the sixth section), which represents a further development of the framework presented by Mignon and Bergek [31].

**Interviews with selected companies**

Representatives of 11 companies were interviewed, with 3–4 representing each sector. Table 1 provides an overview of the companies, their biogas connections and the positions of the interviewees. The road transport sector is represented by companies with large transport use but who have food processing, retail and recycling as their main activities. Among the manufacturing companies, Svenska brasseri can be considered a service company, but in the national biogas statistics that kind of company is included as part of the manufacturing sector. Some of the interviewed companies had substituted fossil fuels with biogas, some were considering such a substitution and some even had advanced plans for it, while other companies had not expressed any interest in biogas. This diversity meant that the companies addressed the matter of biogas from different perspectives and levels of experience. Some companies could reflect on what had led to the substitution as well as the challenges they had experienced, and other companies what had made them not choose biogas substitution.

The interviews were based on an interview guide with questions concerning the companies and their sustainability work and strategies in general, and drivers for and barriers to the use of biogas or other biofuels. The semi-structured set-up allowed for a flexible structure where interviewees were confronted with the same questions mixed with follow-up questions or requests for further explanation depending on the given answers. According to Kvale [39], follow-up questions contribute to an increased quality of information exchange during an interview. Three interviews took place as physical face-to-face meetings, while the rest were performed via video chat or telephone. The duration of the interviews varied between 20 and 70 minutes. The companies were informed about the purpose of the interview and decided who would be interviewed within their company. Two companies were represented by more than one interviewee. The interviewees agreed that their companies’ names could be mentioned. They also had the opportunity to check the quotes and descriptions of what they said to ensure that they had been correctly interpreted.

The interviews were recorded and completely transcribed. To analyze the collected data, we looked for patterns in the collected data and identified relevant and interesting themes that were similar or unique in the different interviews (thematic analysis) [40].

**Drivers for and barriers to biogas use**

Our analytical starting point was the framework categorizing different challenges to the diffusion of renewable
electricity technologies, on a system and actor level, presented by Mignon and Bergek [31], complemented by the drivers for the diffusion of renewable energy technologies [2], while additional literature also supported the identification and specification of the drivers and barriers connected to biogas usage.

**Drivers**

**System level**

The development of market demand for biogas influenced actors’ interest in using biogas and investing in its related technologies [41]. When there is infrastructure in place to facilitate the use of biogas, it is easier to buy into the technology. Many Swedish municipalities have invested in biogas pre-treatment facilities and other types of biogas infrastructure, such as fueling stations, to encourage both public services and private citizens to use biogas. Formal and informal institutional requirements and expectations are also essential for the adoption of renewable energy technologies [42]. Political goals and public-procurement requirements may also bring incentives for adoption of biogas solutions [1]. Environmental objectives can be particularly influential among publicly owned organizations [37]. Economic policy instruments related to biogas production or consumption create often important drivers [43].

**Actor level**

On the individual adopter level, the adoption decision is often influenced by expected concrete benefits for the adopters, which may consist of both economic and non-economic gains. In the traditional economic literature, price advantages [34] and favorable return on investment [44] dominate as fundamental assumptions for adopters’ investments in (energy) technologies. Other economic motives include the long-term possibility for profitability and avoidance of other costs [42]. Some adopters of biogas solutions have sought to strengthen their environmental profile, which could contribute to improved competitiveness through environmental marketing [1]. For companies, symbolic motives are often related to improving brand and profile among key stakeholders such as authorities and customers [42]. Non-economic drivers for adopting renewable energy technologies can be connected to aspirations to exploit resources that are readily available, to become independent of fossil fuels, or to solve practical problems related to waste or pollution [42]. The environmental motives for adopting biogas solutions can, among different adopters, range from reducing greenhouse gases or improving local air quality to being nature friendly. Although such environmental benefits often seem an important motive, they are not necessarily the primary goal and can be entangled with economic motives [45].

**Barriers**

**System level**

On the system level, market-related barriers are induced by the existing market structure, which often favors existing technologies [31]. Biogas and other renewable solutions compete with each other and with fossil-based fuels that, despite being heavily polluting, have the support of strong actors, networks and institutions, which secure profitability and foreseeable risks [16]. Planning and developing renewable energy technologies involve relatively high costs and
particular risks such as technology unreliability and energy price fluctuations, which might deter investors [46]. Deficiencies of physical assets for biogas, such as limited refill infrastructure and fuel supply, inefficiency and limited variety of gas vehicles, as well as of non-physical assets such as lacking knowledge about biogas and differences between alternative technologies and fuels, act as infrastructural barriers to biogas solutions [1]. A particular challenge for biogas solutions relates to unstable policies, institutional misalignment and conflicts between different governance levels or sectors [37].

Actor level
For individual adopters, a lack of knowledge and experience, financial resources, physical resources and social capital brings resource challenges [31]. Knowledge and experience with similar technologies is needed to create absorptive capacity, while financial resources can directly affect the willingness of adopters to invest in renewable energy technologies [47]. Social capital, which relates to legitimacy and access to social networks, is important for accessing information and decision-making support that is central to the adoption of renewable energy technologies [34]. Behavioral characteristics may also influence the willingness to adopt biogas solutions. While innovativeness characterizes early adopters of an innovation, risk aversion is typical for laggards who wait until the innovation is established [34].

Results
All the interviewees were well informed and aware of biogas as an alternative renewable fuel. The companies had different experiences with biogas and other renewable fuels. The road transport companies were actively replacing parts of their diesel use with renewable alternatives but had chosen other renewable fuels and had no immediate plans to adopt biogas. The shipping companies were all looking into options with less environmental impact, but not necessarily renewable options, and none of them had any plans to use biogas. In contrast, the manufacturing companies all used biogas or planned to use it in the near future. Arvid Nordquist and Svenska brasserier had introduced biogas as a substitute for LPG and compressed natural gas (CNG), respectively. Easy access to gas infrastructure had in both cases facilitated the introduction of compressed biogas (CBG). The other manufacturing companies had decided to introduce biogas, but these decisions were not yet implemented. Toyota Material Handling plans to replace LPG with liquefied biogas (LBG). In contrast to the other companies that relied on purchased biogas, Agroetanol planned to use biogas already being produced by the company to replace purchased LPG.

Manufacturing

Drivers for biogas use
The adopters are biogas pioneers in their business areas. Arvid Nordquist was the first company in Sweden to use biogas for coffee roasters. Svenska brasserier owns almost one third of the restaurants using biogas in the country. When Toyota Material Handling introduces LBG, it will also be a pioneer within the Swedish engineering industry.

All companies expressed that environmental actions, such as substituting with biofuels, are important for them. They all described their environmental actions and strategies as anchored in a long tradition with linkages to the ownership, markets and profile of the companies and not a result of recent trendiness. Toyota Material Handling has worked with environmental actions since the 1980s and started to look for a substitute for LPG almost a decade ago, but it was only recently that suppliers could offer a renewable alternative.

Agroetanol, Arvid Nordquist and Svenska brasserie all considered increasing their market competitiveness to be an important driver for considering biogas. Environmental actions such as substituting fossil fuels can be used for profiling as a better environmental alternative and possibly increasing their market shares. Arvid Nordquist believes that their sustainability work is part of the reason why their sales doubled in the last 8–9 years. Agroetanol also expressed that increased competitiveness was important. Its unique selling point is that their ethanol has a higher climate benefit: ‘if it is enough with 35% climate benefit there are others that can deliver it cheaper, who haven’t invested as much as we have in climate efficiency’. The company had decided to invest to enable the use of its unused excess biogas instead of purchased LPG, which brings savings.

Svenska brasserie, in contrast, was not convinced that the company should actively advertise its environmental actions, but said, ‘one would certainly be able to find the economic benefits of switching to biogas, such as marketing benefits, which we have barely done’. Their interviewee stated that ‘sustainability should come as natural for us’, but the restaurants will never use sustainability as their unique selling point. It should be easy to find information about the sustainability work of the restaurant without it being forced on the customers.

Both adopters expressed that the foundation for their sustainability work is that the companies are family businesses to be passed on to the next generation. This was emphasized from the start in the interviews. According to Svenska brasserie, ‘we have a principal owner who always has a 100-year perspective on everything he does and who does not run this business to sell but rather to pass on to his children’. Arvid Nordquist was on a similar track: ‘it is a family business, and I think it’s really important for our thinking … there is a much longer planning horizon where they [the owning family] think that they have been in business for 133 years and may be there for another 133 years’.

Barriers to biogas use
As barriers to biogas use, the manufacturing companies mainly brought up practical challenges they had experienced, which were generally deemed rather surmountable. Arvid Nordquist addressed, in particular, the lack of infrastructure and the unreliability and shortsightedness of the current policies. The factory was located about 1 km from a gas grid. Expanding the grid that last kilometer was not a dramatic requirement and made the company aware of the advantages of the current location. This location is, however, not optimal for other reasons and a future relocation of the facility is possible:
In recent years, national biogas policies have only been fixed for the short term. The current exemption from energy and carbon dioxide taxes for biogas was in 2015 prolonged to 2020, but what will happen after that is not clear. Arvid Nordquist considers this shortsightedness a major problem, since ‘we do not invest for 2 to 3 years, we want to know what it looks like for 10 years’. The decision to substitute LPG with CBG was also made with great hesitation: ‘we think they have to make the decision about further subsidies, but we are not sure that they will do it’.

Toyota Material Handling brought up that there had been subsidies for LPG, which made renewable fuels less economically attractive. Svenska brasserier stated that biogas was expensive, which had been a major concern in connection with the substitution. The company did not have to make any extra investments, and one only needed to develop a new contract and pay the higher price for biogas.

For Agroetanol, the substitution was more challenging since biogas is not compatible with its current system. It requires a rebuilding, we must have other injectors and pipes – separate equipment, not the same as for the LPG. This will bring costs, and a major disadvantage is that production must be stopped at certain stages of the construction. Toyota Material Handling’s system is also based on LPG and will need to be rebuilt, but since only limited changes are needed, this was considered a minor issue.

Road transport
Drivers for biogas use
The three road transport companies had all decided not to introduce biogas as a substitute for diesel. IKEA and Svenska retursystem had instead begun to use HVO in parts of their fleets, which had not brought any additional costs. Arla Foods had introduced a wider portfolio of fuels and used HVO and RME as well as lorries running on ethanol.

Taking market shares by being ‘the environmental alternative’ was the only driver for considering biogas brought up by the road transport companies. This was also strongly reflected in the ambitions of the companies. The entire business model of Svenska retursystem is based on their product having a lower environmental impact: ‘That is what we stand for, we help the industry with its environmental impact – if they change to our products, they can reduce their environmental impact’. According to Arla Foods: ‘it’s part of our image – we are natural, we are the farmer’s company. It’s the earth, the cows, the weather, the natural choice, the natural products. Then we should not pollute the environment’. IKEA was on the same track: ‘we want to differentiate ourselves against competitors by our sustainability policy’.

Barriers to biogas use
Since none of the road transport companies had decided to start using biogas, the experienced barriers to using biogas thus outweighed the drivers.

Arla Foods and Svenska retursystem, like Arvid Nordquist, emphasized the lack of stable policies for biogas and other renewable fuels in Sweden as a complication for substituting fossil fuels. Arla Foods had a bad experience in connection with large investments in RME a few years ago. According to Arla Foods, ‘a directive from EU was suddenly over-interpreted and the taxes raised on RME January 1st, 2015, which completely pulled the rug out from under RME’. The company’s response to this experience has been to not invest in only one alternative: ‘We need to have several fuels – we do not know what’s going on in the future and when I buy lorries, we will have them for 7 years’. Svenska retursystem agreed that sudden policy turns are problematic, bringing up RME and the debate on palm fatty acid distillate (PFAD) in HVO as examples.

Svenska retursystem brought up the existing fleets as a barrier to changing to alternatives such as biogas: ‘Our vehicle fleet looks like this now and in the short term we will continue with the fleet of vehicles we have – they will be worn out by 2025–2026 something and then we will see what’s on the market’. The opportunity to make fast moves to fuels not compatible with the current diesel vehicles was thus restricted to the vehicles’ aging rate.

The companies also addressed specific barriers for biogas technology. IKEA and Arla Foods expressed that there is not enough biogas for a substitution. According IKEA, ‘there is no gas available for transportation purposes…. The areas that biogas is generated in is generally by local communities from waste that they collect, and they use this gas directly in their own public transport systems’. When asked about the price of biogas, the spokespersons at IKEA answered: ‘it is not a matter of it being too expensive or not, it is just not available in many markets’. They had, however, noted the trend of increasing supply of CBG and LBG.

Svenska retursystem stressed more the lack of suitable vehicles: ‘we have mostly long transports…. and then biogas is not good enough’. They had looked at LBG but ‘still feel that it is a bit too far away’. Arla Foods sees a similar difficulty, with the presently available gas-powered lorries and upcoming public biogas refueling facilities not suitable for their direct distribution system.

Arla Foods also brought up negative earlier experiences with gas engines. The company tried to use methane gas in their lorries 10–15 years ago, but this was terminated due to technical problems and limitations.

Shipping
Drivers for biogas use
Among the four shipping companies, there are no plans to introduce biogas. Wallenius Marine is developing LNG ships but has no immediate plans to use LBG in them. Wallenius Marine is also moving toward combustion-free shipping, involving the use of electricity and wind. Stena Line is looking into ships powered by both electricity and methanol, while Thunbolagen is slowly moving toward LNG but has no immediate plans to use LBG. Styrsköbolaget is most likely going to invest in electric hybrids in the future as many companies with similar ferries already are doing.

However, the shipping companies all addressed drivers for sustainability work and using cleaner fuels.
Sustainability is important for Wallenius Marine, Stena Line and Thunbolagen. When asked why they were interested in environmental actions, the interviewee at Wallenius Marine had difficulty understanding the question since the answer was so obvious to him: ‘We need to make the world better’. Stena Line emphasized that their employees expect that they act responsibly. The company thinks that its investments toward more sustainable shipping will eventually pay off: ‘We think it’s an investment that will be profitable over time, even if it will cost money in the short run’. Thunbolagen had a similar attitude: ‘If we focus on sustainability, we will see it as an advantage in the future’.

Like Svenska brasserier and Arvid Nordquist, Wallenius Marine stressed that it is a family company and that the company’s interest in sustainability is backed by the owning family. In contrast, Styrsöbolaget’s business is completely based on public procurement contracts, and its main focus is to follow contract requirements, which also determine the choice of fuels: ‘If the requirement was that we have to have 20, 30 or 100% biofuel – then we would have considered that in our bid’.

**Barriers to biogas use**

As reason for not considering biogas as an alternative fuel, Stena Line, Thunbolagen and Wallenius Marine all explained that biogas is too expensive. According to Wallenius Marine, ‘Fuel is such a large part of the cost that it is not possible to compete if you cannot find a reasonably cheap fuel’. Stena Line explained that part of the problem was that the customers were not ready to pay anything extra for less environmental impact, and Thunbolagen agreed that sustainability is not pushed from the customers as much as could have been hoped for. Another challenge, according to both Stena Line and Wallenius Marine, is that renewable fuels and electricity generally have higher taxation than the regular fossil shipping bunker fuels. Renewable fuels and electricity do not have any subsidies – they can both be taxed. However, Stena Line further explained that the taxes are not solely responsible for the high price of renewable fuels: ‘Even without the tax, renewable fuels today would be far too expensive’.

Another major barrier mentioned by both Stena Line and Wallenius Marine is that biogas cannot be used in common ships. Ships also often have a longer life span than lorries, for example. According to Stena Line: ‘A ferry may be used for 40 years, or sometimes more, so it is an advantage if the fuel can be used in existing ships. Or that the conversion is as cheap as possible’. The shipping companies are thus locked for a long time into current technologies and relegated to compatible fuels.

The shipping companies also pointed to the problem that the volume of biogas produced and available for them is too low. According to Stena Line, a single ferry has an average yearly fuel use on the same scale as the yearly production of the largest biogas producer in Sweden. Thunbolagen explained that, ‘Unfortunately, there are not the volumes required to fuel a whole ship with biogas’. Like Svenska retursystem, Thunbolagen and Styrsöbolaget perceived that LBG is a technique that is not always suitable. Since it requires larger fuel tanks, the ship loses some loading capacity.

Styrsöbolaget’s main concern is to comply with the procurement contracts, and the company sees limited room for action. It will not be able to add any costs, which using biogas usually implies, if the contract does not specify particular environmental requirements.

**Summary of the results**

In Table 2, we present a summary of the drivers and barriers that we identified in the different sectors. The results show that common drivers for companies in all sectors are that environmental actions are important for the companies and that companies can take market shares by being ‘the environmental alternative’. Common barriers were either related to cost (too expensive, or unfavorable policies) or the biogas itself (too little production, not suitable/compatible or a lack of infrastructure).

**Discussion**

We identified some drivers and barriers from previous studies which served as starting points for our analysis of biogas usage in the different sectors. Based on our empirical studies, we have confirmed some of these drivers and barriers but also identified some additional drivers and barriers (Table 3). Below, we discuss these drivers and barriers on the system and actor levels using our empirical findings and previous literature.

**System- and actor-level drivers**

Almost all companies in our study stressed environmental profiling as an important driver, but there are distinct differences between them. Agroetanol and Svenska retursystem have a business model where their unique selling point is being ‘the environmental alternative’, while IKEA, Thunbolagen, Stena Line and Svenska brasserier are more regular companies that are ‘greening’ their activities.

Most companies emphasized that ‘taking market shares by being the environmental alternative’ is an important driver for introducing biofuels. This is an example of an actor-level driver that has economic, environmental and symbolic motivations. The companies strive to build an image as the environmental option (symbolic) by showing a high environmental performance (environmental), to increase their earnings and customer numbers (economic). This multifaceted nature of certain drivers for adopting biogas is corroborated by previous studies on the adoption and use of environmental innovations in general, such as Carillo-Hermosilla et al. [45] who indicated that environmental drivers for the adoption and use of environmental innovations can be entangled with other types of drivers such as economic and symbolic ones. Similarly, Ammenberg et al. [1] found that biogas adopters sought to strengthen their environmental profile and improve profits through marketing.

In some companies, such as Wallenius Marine, environmental actions were viewed as important without necessarily bringing any market advantages. Environmental actions relate to the perceived positive impact of the adoption of an innovation, and depending on the type of adopter their environmental drivers can range from
reducing greenhouse gases to improving local air quality to being nature friendly, as found in previous studies [e.g. 48]. The two companies in our study that had already changed to biogas emphasized the fact that they are family-owned businesses with an inherent long-term perspective as a strong

Table 2. The drivers and barriers experienced by the companies in the studied sectors.

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Table 3. Summary of identified drivers for and barriers to the diffusion of biogas in the manufacturing, shipping, and road transport sectors. The drivers and barriers confirmed by our results are presented in bold.

**Drivers**

*System level*

- Steady demand for biogas
- Existence of biogas production facilities
- Existence of gas grids
- Existence of fueling stations
- Subsidies (tax exemptions, exemptions from parking fees, congestion fees, subsidies for production)
- National, regional and local climate goals

*Actor level*

- Economic gains
- Non-economic gains
- Stakeholder requirements
- Existence of biogas production facilities
- Contributing to environmental goals at different societal levels
- Improving social status
- Branding
- Green profiling
- Values/norms

**Barriers**

*System level*

- Dominance of fossil fuel incumbents
- Lack of physical infrastructure
- Lack of biogas
- Lack of competence, capability, resources or capacity among technology developers
- Investment costs, risks and returns
- Availability and access to capital
- Unfavorable policies
- Stakeholder interactions
- Lack of knowledge
- Dissatisfactory experience
- Limited financial resources
- Incompatibility with physical resources
- Lack of social capital
- Values/norms
- Characteristics of potential adopter
- Strategies of potential adopter

*Actor level*
driver for introducing biogas. Wallenius Marine also emphasized that their sustainability work was pushed by the owners, but they are looking at other renewable fuel options such as wind and electricity. The importance of an intergenerational perspective in connection with strategic decisions is not often mentioned in the renewable energy adoption literature and is in sharp contrast to observations that short- to mid-term economic gains dominate industrial action. The traditional energy economics literature tends to assume that investments in energy production technologies are driven strictly by short-term profitability and return on investment [49].

Public procurement plays an important role in the diffusion of biogas solutions since such processes may specify environmental requirements, which the supplier has to meet [37]. Styröbolaget said that it would change to an environmental alternative if the procurement had such specifications. Ammenberg et al. [1] argued that public organizations are central actors in the development of renewable energy, and highlight the example of the public transport company in Stockholm, which uses public procurement to phase out fossil fuels and to guarantee that biogas demand does not decrease. Similar to some earlier studies, we also found one adopter, Agroetanol, that adopted biogas based on its own resources that were available to exploit.

System- and actor-level barriers

Like other renewable energy technologies, biogas solutions compete with fossil technologies that do not always pay their full societal cost [50]. Since biogas solutions are often more expensive, they depend on subsidies and tax exemptions to be able to compete. Unstable policies were stressed as an important barrier for making investments by several companies. Fenton and Kanda [37] and Ammenberg et al. [1] identified unstable policies as a barrier to the adoption of biogas solutions in different contexts (Stockholm, Sweden; Odense, Denmark; and Basel, Switzerland). Ammenberg et al. [1] found that the majority of the actors they interviewed described the biofuels policy landscape as very dynamic and uncertain. Fenton and Kanda [37] showed that renewable energy policies are unstable, short-term and changing, and also identified conflicts between governance levels. Our interviewees mentioned only few examples, but one episode was brought up of a sudden change in national policy as a response to a previous bad experience. Ammenberg et al. [1] found that some of the rules for public procurement processes can be barriers or drivers depending on the circumstances. The supplier must meet the environmental requirements specified in the procurement [51]. Fossil fuels are tax exempt worldwide in connection with shipping, and LPG use in manufacturing was previously exempted from taxes in Sweden.

Three of the four shipping companies declared that biogas would simply be too expensive for them. Svenska brassserier did not need to make any initial investments, but their biogas substitution still brought an extra cost of almost 50,000 Euros per year. Other types of motivations, such as the identity and long-term perspective of the company, were thus needed to lead to substitution.

The limited infrastructure for biogas is an important system-level barrier. In regions with no gas grid in Sweden, it can be expensive to buy biogas since it has to be transported by lorries. All companies that used biogas or planned to introduce biogas have a gas grid connection, produced their own biogas or were situated close to a biogas production plant.

Another system-level barrier is that there is not enough biogas produced to meet the demands of potential users, which was stressed by many of the transport and shipping companies. Much of the current biogas production is not available for sale since it is reserved for public buses. To increase the biogas production and distribution capacity to fit large potential users is a demanding challenge considering the current structure of production and distribution. Production is limited, dominated by small-scale producers, and markets are most often only local or regional. The biogas market is small and biogas is only produced in small quantities, and there is not much incentive to scale up production since the market is limited. To break this evil circle, large customers willing to issue long-term contracts to secure pay-offs for important investments are crucial.

Another actor resource barrier is that sometimes biogas is not compatible with the current system. Actors have already made investments in lorries, pipes, burners, etc., which are not always compatible with biogas. If these investments have not yet paid off, there are no economic incentives to change.

Biogas technologies, like biogas-driven lorries, are still being developed and improved. Current lorries do not meet the requirements of the transport companies. Biogas lorries have had limitations concerning use for long-distance transport, and their fuel efficiency is often viewed as a major challenge [1]. However, the newest lorries can drive 1000 km on liquefied biomethane without refueling [52]. So, in the future, this may not be a barrier to adoption.

Previous bad experiences can be an important behavioral barrier at the actor level since experiences tend to influence adopters’ attitudes toward an innovation and their likelihood to adopt it [32]. Arla Foods’ failure with methane-powered lorries 10–15 years ago still forms an important barrier for biogas solutions within the company, even if the company would most probably not encounter similar problems since biogas lorry technology has improved considerably.

Public procurement often plays an important role in the diffusion of biogas solutions, but where no requirements are specified, companies will not do anything extra because their offers need to be financially competitive. If procurers do not require biofuels, not much will happen – as the case of Styröbolaget demonstrates. Ammenberg et al. [1] found that some of the rules for public procurement may limit the possibility to require the fuels that are considered best from an environmental perspective.

Interaction between system and actor levels and different sectors

The different drivers and barriers interact through synergies and sometimes conflicts. Contract requirements in public procurement processes can be barriers or drivers depending on the circumstances. The supplier must meet the environmental requirements specified in the procurement but has no incentives for additional actions. The lack of a gas grid often serves as a barrier, while access to a gas
grid can be a significant driver. The companies that already had switched to biogas had access to gas grid, and there are other examples of factories already connected to the gas grid that have introduced biogas [23]. To the best of our knowledge, no industries have started to use CBG without gas grid connection. The systemic condition of infrastructure availability thus influences the adoption of biogas solutions and sometimes investments in grid extensions.

In some cases, drivers for one actor can become a barrier for others. For example, contract requirements in a public bus procurement process can force buses to use the biogas produced by the municipalities [1]. However, this may decrease the amount of biogas reaching the market, and thus be a barrier for other companies that are potentially interested in using biogas.

The environmental, symbolic and economic motivations for adoption are inter-linked drivers for the companies in our study. Their most important motive to engage with biofuels is that they find it a way to increase their competitiveness by being ‘the environmental alternative’. This motivation is not purely environmental, symbolic or economic, but a mix of the three. Similar observations have been made with other types of renewable energy technology adopters (e.g. wind, solar, hydro) [2].

Companies in all sectors found that biogas is not compatible with their current systems, and the price of biogas and uncertain policies were important barriers. Road transport seems especially affected by unreliable policies, while the manufacturing companies are more divided – one company considered the policies unreliable and short-sighted, while another found that the policies reward other fuels more and a third stated that biogas is too expensive. The shipping companies all shared the view that biogas is too expensive and that existing policies (e.g. the global tax exemption of fossil shipping fuels) favor fuels other than biogas. This observation adds weight to earlier studies that stress the importance of policy in shaping biogas markets [e.g. 1,16,37].

The limitations of biogas supply were viewed as a barrier by several different companies, but this was particularly emphasized by the shipping companies with large vessels. Considering that the yearly fuel demands of single large ships are greater than the annual production from the largest biogas plants, this was not unexpected. Only manufacturing companies mentioned lack of infrastructure as a barrier, but in contrast to road transport and shipping, they are bound to single locations and more directly affected by the available infrastructure at that particular location. Only one company had negative previous experiences that affected their willingness to use biogas. That this was a road transport company was not surprising since biogas has a longer history in road transport, and the technology was fairly unreliable when it was introduced. Styrsöbolaget, unique due to its reliance on public procurement, was the only company that mentioned contract requirements as a driver and a barrier.

Conclusions and policy implications

The findings of our study on the major drivers for and barriers to increased biogas usage in road transport, manufacturing and shipping in Sweden confirm several of the drivers and barriers identified in previous studies related to the potential for increasing the use of renewable energy. Several of the drivers and barriers identified, such as unstable and short-term policies, lack of infrastructure and contract requirements, and economic and environmental motivations, were also found in previous studies. The inter-generational thinking in family-owned businesses as an important driver for adopting biogas or other renewables is not observed in the earlier literature, which often stresses evaluation of profitability and return on investment as the major economic drivers [e.g. 53]. This study also identifies some types of drivers and barriers in relation to biogas that are particular to one of the three sectors.

Our study provided empirical evidence that both system-level drivers (such as the steady supply and demand for biogas, existence of infrastructure, and favorable and stable institutional conditions) and actor-level drivers (such as economic gains connected to green profiling, making use of available resources, cost savings and environmental benefits) were of importance for shifting to biogas from fossil-based energy sources. For a general increase of biogas usage, a steady and radically increased supply of biogas seems necessary, since some of the potential users of biogas have demands that are higher than the current production of the largest biogas producers. The availability of biogas in liquid form, together with widespread development in infrastructure and technology (e.g. new lorries and ships), and favorable institutional conditions for the production and use of biogas are altogether necessary pre-conditions for an expansion of biogas usage.

For policymakers, the findings from this study have several implications. The empirical findings support previous studies that identify policies as a major driver for the increased use of energy from renewable sources in general and biogas in particular. This study argues that the potential to increase biogas usage in the economy lies not only in existing use areas such as public buses and private cars but also in other sectors where the usage of biogas has been rather marginal. When formulating policies to stimulate the increased use of biogas, policymakers should also consider incorporating the drivers and barriers for biogas usage in such future usage areas.

Furthermore, our study also highlighted that there are some drivers for and barriers to biogas usage which are specific to the different sectors. In shipping, the fuel costs represent a more significant share of the total operational costs than in the manufacturing and road transport sectors. The lack of infrastructure such as gas grids is particularly connected to the manufacturing sector as the factories are located at specific sites and cannot relocate easily. For policymakers, this suggests that one-size-fit-all types of policies will not be appropriate, but rather there should be careful consideration of the different mixes of barriers and drivers in connection with development of policies. On the individual adopter level, some adopters are driven by economic benefits while others have sustainability, green profiling or long-term survival as part of their core business. These differences in adopter drivers will also need to be considered in connection with policies to stimulate increased biogas usage.

Altogether, the results of this study suggest that there is a need for more ambitious policy strategies guided by
long-term trajectories and experimentation. Policies with long-term trajectories will provide a stable basis for adopters to make investment decisions regarding biogas and other renewable technologies. On the other hand, to prevent lock-in to sub-optimal energy solutions, there is a need for policy experimentation and diversification. In particular, policymakers face challenges regarding the choice of technologies to support since there are several renewable energy technologies such as solar, wind and hydro power, with different degrees of maturity, that seek to compete with and replace fossil-based energy. Therefore, policies should be guided by both differentiated support for different types of renewable energy technologies and the possibility to redeploy support from mature to immature technologies (and also to withdraw support from energy sources with high external costs).

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