POLICY FOR BIOMASS UTILISATION IN ENERGY AND TRANSPORT SYSTEMS – THE CASE OF BIOGAS IN STOCKHOLM, SWEDEN

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ABSTRACT

This interdisciplinary paper explains how biogas policy processes affect energy and transport systems in Stockholm, Sweden. The aim is to discuss future implications of the political biogas agenda, and analyse how municipal organic waste should be utilised to achieve greenhouse gas emission reductions. An energy systems analysis illustrates the environmental impact of biogas production and utilisation, while planning practice and political attitudes are studied in interviews with policymakers. Conclusions include that demand for biogas as vehicle fuel and the influence of particular actors has led to an extensive political campaign for biogas. However, to maximise emission reductions, Stockholm’s waste should ideally be used to produce electricity, not biogas. With the current narrow system perspective and lack of long-term strategies, increased utilisation of renewable fuels in the transport system may be impeded.

1. INTRODUCTION

For a transition to a sustainable transport system, use of renewable fuels must increase. Within the European Union (EU) the Renewable Energy Directive (RED) establishes that member states shall achieve a share of 10% renewable energy within the transport sector by 2020 (1). In Sweden, biogas is an increasingly popular renewable fuel and many regions, including Stockholm, wish to increase both production and consumption of biogas.

Stockholm County, Sweden’s largest urban area, is situated in eastern Sweden. The number of methane-fuelled buses and passenger cars is steadily increasing within the region (2-3). Coincidentally, the region’s biogas production has increased, mainly in sewage treatment plants, although interest in using municipal organic waste (MOW) as a substrate has also escalated (4). The latter requires source separation and collection of MOW, which is currently mainly collected with other municipal waste and incinerated in combined heat and power (CHP) plants (5). For more details about biogas, see Fig. 1, and about Stockholm, see Fig. 2.

Stockholm region facts and figures:
2,000,000 inhabitants.
Passenger vehicles: in total 820,000; of which 1.5% are methane-fuelled. 3% of 2011’s new vehicle registrations are methane-fuelled.
Public transport: 7% of regular traffic buses are methane-fuelled.
Biogas production: 250 TJ annually.
Biogas consumption: 610 TJ annually.
Heat delivery in DH grid: 43 PJ annually.
Electricity production in CHP plants: 7 PJ annually.

Fig. 1: Biogas in brief. Source: (6).

Fig. 2: Stockholm region in brief. Sources: (2-4, 7).

The increase in biogas production and consumption is partly the result of an extensive political process concerning increased biogas production. Biogas is the only renewable vehicle fuel to which all actors in the region have turned their attention and agreed to produce. Public authorities mainly seem interested in biogas as vehicle fuel (4), but alternatives exist. Both biogas and MOW may be used in heat and power production. Two waste-fuelled CHP plants are connected to Stockholm’s large district heating (DH) grids (7), and three new waste-fuelled CHP plants are planned (8-10). The conflict between alternative options for utilisation of MOW and biogas, in contrast to the political agenda, may influence the development of both the energy and transport systems in the Stockholm region.

Biogas facts:
Biogas: upgraded from raw biogas; 96-99% methane; utilised as vehicle fuel.
Raw biogas: produced from anaerobic digestion of biomass; 50-80% methane and 20-50% carbon dioxide; utilised in heat and power production.
Residual product: digestate, utilised as fertiliser.

Fig. 1: Biogas in brief. Source: (6).
1.1 Aim

This interdisciplinary paper explains how biogas policy processes and biogas-related infrastructure development affect energy and transport systems in Stockholm, Sweden. The aim is to consolidate an energy systems analysis, regarding CO$_2$ emissions from MOW and biogas utilisation, and an analysis of a political process, in order to recognise implications for future energy and transport systems.

Research questions to be answered are:

- Why is there such an explicit focus on biogas on Stockholm’s political agenda?
- How should substrates and biogas be utilised, according to technical possibilities and political objectives?
- What implications does Stockholm’s biogas campaign have for future energy and transport systems?

The area covered in this paper is usually analysed from either a technical or a social scientific perspective. Treating the issue of biogas as a socio-technical system, in which the interaction between society and technology is acknowledged, enables a fuller understanding of the intrinsic complexities of the system.

2. METHOD

A combination of interviews and energy systems analysis is used. The research questions are analysed using results from both kinds of methods. This kind of analysis facilitates the understanding of consequences from political choices and technical realities, which affect the transition to a sustainable future.

To describe the political process regarding biogas in Stockholm and the understandings on which it is based, qualitative interviews were performed with six stakeholders. Three of them are involved in biogas development in the Stockholm region, and three work with issues regarding development of a completely sustainable transport system in Stockholm. The interview respondents are presented in more detail in Table 1. The interviews were semi-structured and with a low level of standardisation. They lasted for about an hour and were recorded and then carefully transcribed.

To illustrate implications of biogas production, the impact of energy conversion is analysed with respect to greenhouse gas (GHG) emissions. MOW is the only analysed substrate, as sewage sludge is already used at near maximum capacity and other substrates are not abundant in the Stockholm region. Output alternatives are raw biogas utilisation for heat and power production, biogas utilisation in vehicles and waste incineration in CHP plants. This is illustrated in Fig. 3.

![Fig. 3: Biogas production options in an urban context.](image)

Which conversion technique is best from a GHG emissions perspective depends on the system boundaries chosen. To demonstrate the importance of system perspective, emissions are presented using two perspectives. Emission reductions are often presented using the vehicle as system boundary, where only tailpipe emissions are accounted for. Here, alternative utilisation of biogas is also presented, using a marginal perspective.

### TABLE 1: INTERVIEW RESPONDENTS

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Title</th>
<th>Workplace</th>
<th>Role of importance for this paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>(11)</td>
<td>Politician</td>
<td>Municipality in the Stockholm region</td>
<td>Political representative of Stockholm County Association of Local Authorities regarding biogas</td>
</tr>
<tr>
<td>(12)</td>
<td>Senior Administrator</td>
<td>Stockholm County Assoc. of Local Authorities</td>
<td>Official representative of Stockholm County Association of Local Authorities regarding biogas</td>
</tr>
<tr>
<td>(13)</td>
<td>Chief Executive Officer (CEO)</td>
<td>Publicly owned water company in the Stockholm region</td>
<td>Head of a company producing biogas and former representative of the Stockholm region’s water companies assoc. in the biogas policy process</td>
</tr>
<tr>
<td>(14)</td>
<td>Project Manager</td>
<td>City of Stockholm</td>
<td>Works with introducing ethanol, biogas and electricity as vehicle fuel in Stockholm</td>
</tr>
<tr>
<td>(15)</td>
<td>Overview Planner</td>
<td>City of Stockholm</td>
<td>Works with Stockholm’s City Plan</td>
</tr>
<tr>
<td>(16)</td>
<td>Analyst</td>
<td>Stockholm County Admin. Board</td>
<td>Works with the issue of renewable fuels in Stockholm County, with focus on biogas</td>
</tr>
</tbody>
</table>
This method of accounting for emissions takes into account that new production of energy carriers replaces marginal energy carriers (17).

![Fig. 4: Alternative utilisation of MOW and biogas. Dashed lines represent energy sources which may be replaced.](image)

When used as vehicle fuel, biogas replaces petrol in light-duty vehicles (LDV) and diesel in heavy-duty vehicles (HDV). Alternative utilisation includes the utilisation of waste or biogas in CHP plants. As new CHP capacity is planned, utilisation of waste or biogas in CHP plants is assumed to increase CHP production, replacing marginal coal condensing (CC) power. When using waste or biogas for CHP production, vehicles are assumed to run on petrol or diesel. When using biogas as vehicle fuel, marginal CC power is not replaced. See Fig. 4 for an illustration of this concept. With new CHP capacity, marginal heat production may also be replaced. This paper, however, takes only electricity and vehicle fuels into consideration, not heat production. Table 2 summarises figures used to calculate direct GHG emissions. These figures include emissions from MOW collection, MOW transport and biogas plant operation, but exclude emissions avoided from e.g. methane leakage from substrate storage. Fossil fuel figures include the same kind of life-cycle emissions.

### TABLE 2: LIFE-CYCLE GHG EMISSIONS OF FUELS

| Fuel            | g CO₂ eq/MJ output
d | g CO₂ eq/kg substrate |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste, CHP³</td>
<td>2</td>
<td>44</td>
</tr>
<tr>
<td>Raw biogas, CHP³</td>
<td>14</td>
<td>44</td>
</tr>
<tr>
<td>Biogas, LDV³</td>
<td>97</td>
<td>66</td>
</tr>
<tr>
<td>Biogas, HDV⁴</td>
<td>52</td>
<td>66</td>
</tr>
<tr>
<td>Petrol, LDV⁵</td>
<td>475</td>
<td></td>
</tr>
<tr>
<td>Diesel, HDV⁴</td>
<td>191</td>
<td></td>
</tr>
<tr>
<td>CC⁶</td>
<td>292</td>
<td></td>
</tr>
</tbody>
</table>

³ ‘Output’ includes electricity, heat and kinetic energy.

⁴ Source: (18-19)

⁵ Source: (18)

⁶ Source: (20)

⁷ Source: (17)

3. RESULTS

3.1 Biogas on the political agenda

Biogas became a prioritised issue on the Stockholm region’s political agenda around 2007. At this time, a regional process to influence local governments to initiate source separation and collection of MOW started (11). However, discussions about increased biogas production began earlier. The water and waste companies’ interest organisations started negotiations on source separation and collection of MOW. The water companies saw biogas as a possibility to make a profit, since they had overcapacity for anaerobic digestion in their sewage treatment plants which they would be able to fill with MOW. However, a collective solution could not be agreed upon. In 2007, several other organisations joined (13). This larger planning group started influencing local municipalities to initiate MOW collection, investing in biogas production plants and utilising the overcapacity of sewage treatment plants (11).

Respondents claim that there are several reasons why biogas became an important issue on the political agenda. However, the main motive was lack of biogas supply within the region (11-16). The increasing biogas demand was an issue brought up both by local media and by national authorities. The County Administration Board published a paper concerning possibilities for regional MOW collection (16). In addition, one of the largest newspapers published a series of articles about lack of biogas in Stockholm, and the possibilities of an increased supply from MOW (11). Both were important influences for regional actors to initiate a planning process (11, 16).

Other aspects also explain why the process started; the importance of influential actors is one of them. The water companies recognised a lucrative new business. Biogas production has changed their business logic; earlier they were financed by fees, but with biogas production their business has become profitable (13). This new possibility is important for their engagement in the biogas policy process (13).

"Of course, it is also for strictly economic reasons [that we have started biogas production], since this means that we may benefit from an investment with capacity for lower costs of water treatment." (13)

Other influential actors considered important for the biogas policy process in the region are individual politicians and civil servants who are interested in environmental issues and very committed to the development of biogas for vehicle utilisation. They emphasise the importance of working to solve climate problems and realising the serious problems caused by fossil fuels in the transport sector. For them, the climate problem is the most important motive for biogas production (11, 13). They are stakeholders in the biogas policy process and act as entrepreneurs believing in their product when trying to “sell” the idea of MOW collection and increased biogas production to the municipalities.

The most successful argument for regional biogas
development is that waste is transformed into a resource. Large waste volumes and increased local emissions in the city make fuel production an interesting option (11-16).

“What is fun really, I think, is that in a way we get...if we produce biogas from waste we actually get a locally produced fuel.” (11)

Utilising Stockholm’s MOW makes biogas a locally produced fuel, interesting both because it sounds good from an environmental perspective (13) and because it strengthens energy security (11).

There is no national strategy regarding biogas use in Sweden, but there are legislation and policy objectives which respondents emphasise as important in the planning process. A national environmental quality objective to treat 35% of organic waste biologically was a successful argument in the negotiations to convince opponents to use MOW for biogas production (11). Thus, national policy did not put biogas on the political agenda, but it helped keep it there.

3.2 Utilisation of substrates and biogas

Discussing biogas utilisation requires availability of biogas. This raises the question of alternative utilisation of substrates. As described above, in the Stockholm region discussions concerning increased biogas production revolve around the substrate MOW (11-16). Today, most organic waste is incinerated in CHP plants (5) and thereby converted to power and DH. Major DH grid owners plan to increase their already large waste incineration capacity (7). A study by Holmgren and Henning (19) shows that MOW incineration is nearly three times more energy efficient than biogas production from the same amount of MOW. Hence, in areas with DH grids, incineration may be more energy efficient than anaerobic digestion.

An alternative is to utilise raw biogas in CHP production. Most Swedish biogas-producing farms and sewage treatment plants use their biogas in heat and power production (21). However, Swedish policy values GHG emission reductions ten times higher when achieved within the transport sector than when achieved by CHP production (22). Also, selling biogas as vehicle fuel is currently more profitable than selling heat and power produced from raw biogas (23). Petrol and diesel prices tend to increase steadily, while the electricity price fluctuates, which suggests that this relationship may continue (24-25). Investment in upgrading facilities is costly, but guaranteed offset of biogas may enable the investment. For example, some of Stockholm’s biogas producers have made long-term deals for delivery to the public transport company (13).

As stated earlier, reasons for increasing biogas production in the Stockholm region were largely economic. The analysis of the interviews suggests that the issue of GHG emissions and climate change is not really a main motivation, although respondents mention it. From an EU perspective, however, climate change mitigation is one of the main reasons to increase the use of biofuels in the transport sector (1). When considering only GHG emissions from vehicles, it is easily assumed that replacing fossil fuels with biogas reduces emissions. This scenario is illustrated in Fig. 5, where the GHG emission reductions from utilising biogas from MOW to replace fossil energy are displayed.

Fig. 5: Emissions from utilisation of biogas from 1 kg MOW – not accounting for alternative utilisation. (LDV = light-duty vehicle; HDV = heavy-duty vehicle)
Berglund (6) suggests that the environmental impact of biogas systems is most beneficial when indirect effects are considered. In the previous examples, indirect environmental effects, concerning e.g. local air pollution or digestate utilisation, are not accounted for. For instance, reduction of artificial fertiliser use through use of digestate helps reduce GHG emissions (since production of artificial fertiliser utilises fossil energy [6]). Therefore, GHG emissions from biogas utilisation may be reduced even further. The value of reducing local pollution, from e.g. particulate matter, by replacing fossil vehicle fuels, cannot be translated into CO$_2$ equivalents but may also be considered an important environmental factor.

Stockholm is not the only Swedish region with consensus on producing biogas from MOW. Lack of a national strategy, directing MOW utilisation and biogas production, makes this a complicated regional or local discussion, and decision-making is often based on other regions’ experiences and knowledge (11). Other Swedish regions started biogas production earlier than Stockholm (26). The reason for Stockholm’s slow start is connected to the discussion of MOW utilisation. When the biogas policy process started, involved actors could not agree on how MOW should be utilised – for biogas production or for incineration in CHP plants. Initially, many actors supported incineration, but they were eventually marginalised. This opened up the possibility to put biogas on the political agenda and start a planning process (11).

In addition, the interviews reveal a conflict regarding utilisation of biogas as vehicle fuel. As mentioned before, current biogas demand exceeds supply. The demand is met by biogas from other Swedish regions and natural gas (4). This relationship is assumed to continue, even with increased production in Stockholm. According to Lantz and Börjesson (27), Stockholm’s biogas potential is merely enough to serve 50% of buses in regular traffic. In this calculation, no biogas is distributed to taxis or private passenger cars. Respondents emphasise the importance of discussing who gets the right to utilise biogas (11).

“This gap [between supply and demand] increases continuously, and we should not think that surrounding regions will generate a lot of biogas for us […] so I believe that in the future, we need to consider some kind of prioritising. I think that we need to have that discussion.” (11)

One respondent argues that public authorities should restrict the utilisation of biogas to buses in regular traffic, taxis and garbage trucks that traffic Stockholm’s city centre (11). The reason is reduction of local emissions; biogas-fuelled vehicles emit only 8% as much particulate matter as diesel-fuelled equivalents (28). Another advantage is that biogas-fuelled buses are less noisy than diesel buses and therefore fit the urban environment better (11).

This prioritisation may affect private persons who have invested in biogas-fuelled vehicles. However, one respondent argues that private persons should not drive biogas-fuelled vehicles, assuming that electric vehicles (EVs) will be a much better choice when fully commercialised (11).

“Most people would be able to manage with electric cars. Because most people drive very, very short distances.” (11)

Prioritising biogas utilisation in public transport has already implicitly started. Two out of three major biogas producers are restricted by their owners (the municipalities) to distribute their biogas to public transport only (13). This restriction is a result of those municipalities’ governing parties’ political ideology, as
they believe that publicly owned companies should not compete on a free market.

3.3 Implications on future energy and transport systems

The subject of renewable fuels and alternative vehicle technologies is much debated in Sweden as well as in the Stockholm region. Studies show that in order for Stockholm to reach a sustainable transport system, a variety of measures, e.g., changed travel patterns and diversity of fuels, is needed (29-30). Many renewable fuels (e.g., biogas, ethanol, biodiesel) and alternatives to internal combustion engine vehicles (e.g. plug-in EVs) are under development, and it is likely that a sustainable transport system needs to incorporate several of these options (29). However, respondents assume one or two fuels to dominate a future system based on renewable fuels (11-16). Currently, biogas, ethanol and EVs dominate the discussion, in which ethanol and biogas are discussed in terms of current use, while EVs are considered a future solution (11-16).

Respondents do not consider biogas a long-term solution, but rather a fuel which will be widely used in 10 to 30 years but not thereafter. Expectations are that EVs are the future solution and that in 10-30 years they will be common (11-16).

“I believe that biogas cars are a transition. It is not that in 30-40 years the biogas car will be a big thing, but hopefully, electric [car] technology is applied so that electric cars form the great, most interesting source.” (11)

One reason why EVs are politically popular is connected to Stockholm’s congestion problem, which contributes to local pollution (29). Since most daily travel is shorter than 50 kilometres (29), the plug-in EV is an attractive future solution both due to the limited range required and because of very low local noise and zero tailpipe particle and GHG emissions.

Current transport system energy use is restrained by lock-in. The Stockholm discourse suggests that this may prevail even in the transition to a more sustainable system. Biogas producers are optimistic, however, arguing that production processes can easily be converted. When EVs have taken over the market and biogas is no longer needed as vehicle fuel, biogas producers will easily be able to adjust from fuel production to electricity generation. One respondent claims that there are no risks involved in developing biogas production systems (13).

“So there are no risks in building [biogas production] systems, only opportunities. And I think it is quite nice when a new industry is started, so this is far-sighted.” (13)

Even if policy-makers interviewed in this study want biogas to be the principal renewable fuel only short-term, biogas infrastructure is likely to develop further during that time span. Studies of technology evolution show that a development in infrastructure often leads to a continuation of the system’s expansion on its own, difficult to adjust even if policy-makers would like to change directions (31-33). This biogas path-dependency might therefore obstruct the development of a more diversified renewable transport system.

4. DISCUSSION

Biogas became an issue on Stockholm’s political agenda when demand exceeded supply; water companies recognised a business possibility; the advantages of waste becoming a resource were communicated to policy-makers and the public; and when national policy was found as a good argument for biogas production from MOW. Even though respondents argue that it was concern for the environment and the climate that was the main reason, the analysis made in this paper points towards the issue of biogas demand and the possibilities for biogas producers to profit as the main reasons. Biogas on the political agenda might be framed as a climate issue, but instead it is based on profit interests. Due to lack of both knowledge of technical realities and national guidelines, individual actors may become influential and are able to shape the system according to their interests.

In Stockholm, the renewable fuel discussion is entirely focused on production of biogas from MOW and on consumption of biogas as vehicle fuel. Politically, this is the only option, even though alternatives exist. This attitude has two problems: it is based on political opinion rather than on systems analysis of the issue, and it is of a regional nature. Lack of national strategies concerning renewable fuels enables regional politicians to act independently, without much concern for future consequences or for how the issue is handled in other regions.

As has been shown in this paper, utilising biogas as vehicle fuel is not the best option from a GHG emission reduction perspective. Including energy utilities within the system boundary gives the result that incinerating MOW reduces GHG emissions more than producing biogas and fuelling vehicles. Hence, incinerating MOW in already established or planned CHP plants is a preferable scenario. From an environmental point of view, reducing MOW volumes (i.e., wasting less food), should also be considered.

Biogas may still be used as vehicle fuel, but perhaps produced from agricultural waste products such as manure, which is plentiful in Sweden if not in Stockholm. Gasification of woody biomass, a resource also abundant in other Swedish regions, could in the future produce large amounts of synthetic natural gas which could...
complement biogas. Hence, Stockholm’s transport system could utilise renewable methane although the production would occur outside the region. National guidelines regarding biogas production could be useful. The influence of local interests, from potential producers and other individual actors, which has been extensive in the Stockholm region, might be restricted by such guidelines.

The European Commission’s white paper on transport recognises the need for common policy: “Coherence at EU level is vital – a situation where (for example) one Member State opted exclusively for electric cars and another only for biofuels would destroy the concept of free travel across Europe” (34: 5). The different biogas policies within different regions in Sweden might cause a lack of coherence within national borders. The question to ask is then: how will the EU reach coherence regarding fuels, when even a small Member State is not able to do this?

According to policy-makers interviewed in this paper, biogas should be used in buses, garbage trucks and taxis. However, this strategy has not been communicated to the public. Methane-fuelled private passenger cars exist and are bought and driven by private persons wishing to drive without fossil fuels. In other parts of Sweden biogas is promoted as fuel not only for buses and taxis, but for private passenger cars as well, which may influence Stockholm’s private citizens. This way, information spreading from biogas proponents has led to increased biogas demand and thus to lack of supply. This causes a demand for increased biogas production which may force policy-makers to make decisions to increase biogas production, even if it does not coincide with objectives of the long-term transport policy in the region. This could result in a regional path-dependency of only one renewable fuel. Hence, developing and operating a methane infrastructure leads to focus on biogas as the renewable fuel, in competition not only with fossil fuels but also with other renewable alternatives.

This paper has identified several problems originating from Stockholm’s current political agenda on renewable fuels. Policy-makers are shown to have a short-term and narrow focus, concerning only one fuel at a time. They are keen to govern who gets to utilise the fuel, and they are only concerned with the situation within the Stockholm region. Individuals are shown to have great influence over the system, even when their objectives differ from those of the community.

In order to achieve a more sustainable transport system, this political lack of system perspective cannot continue. Policy-makers need to consider greater systems, taking additional technical, geographical and time aspects into consideration before launching their agendas. The ability to utilise systems analysis when developing policy would reduce the risk of biogas path-dependency and lead to a greater diversity of fuels, which is regarded as integral in a more sustainable transport system.

Recognising that other Swedish regions may experience the same difficulties as Stockholm, a firm national strategy for biogas and other renewable fuels could be helpful. With clear objectives and long-term policy suggestions, the Stockholm region could implement such a strategy to fit their specific situation.

5. CONCLUSIONS

This paper has put an interdisciplinary perspective on how biogas policy processes and related technological development affect energy and transport systems in Stockholm, Sweden. It has been shown that biogas production came to be an important part of the political agenda due to increased demand for biogas as vehicle fuel. In addition, potential biogas producers, with economic interest in producing vehicle fuel, were quite influential. In Stockholm, there is political consensus to utilise biogas as vehicle fuel. However, applying a systems perspective, where alternative utilisation of substrates and biogas is considered, shows that incinerating MOW in CHP plants achieves greater emission reductions than producing biogas for utilisation in vehicles. Stockholm’s biogas campaign may inhibit the transition to more sustainable energy and transport systems, emitting less GHGs. In order to avoid this, policy-makers should apply a greater system perspective before launching their agendas. Also, individuals’ influence on the political agenda should be moderated. A firm national strategy for renewable fuels could facilitate these measures.

6. ACKNOWLEDGEMENTS

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