Biogas solutions in the region of Jönköping

- Potential for production and market

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Abstract

The aim of the study was to investigate the biogas potential within Jönköping County both from a production view and a market perspective. A secondary objective was to propose a new biogas plant for the region.

The study was made through literature research, contact with the municipalities and geographical searches. For the biogas potential, two different scenarios were constructed – one realistic and one utopian scenario. The market was investigated by observing the use fossil energy in the region, primarily focusing on the transport sector but partly also on industries. A plan for a new biogas plant was constructed by looking at the available substrates, where they were situated and attempting to find connections with current biogas solutions or cluster of farms.

In the study, several types of substrate fractions were identified – manure, municipal food waste, agricultural residues and waste streams from industries (pulp and paper and food productions). The highest potential came from cow manure as substrate, with a biogas potential of 133-230 GWh/year in the realistic scenario and between 355-613 GWh/year in the utopian scenario. The total potential for the region was 215-330 GWh/year when looking at the realistic scenario and 460-740 for the utopian scenario.

Currently, large parts of the biogas produced in the region is used for public transport. However, there are far more fossil fuels being used in the transport sector in the region than can substituted with biogas – even at a utopian increase of the biogas production. Primarily, the fossil fuel is used for cars and heavy trucks. There seems to be a connection between gas-driven cars and the number of CBG refueling stations, and there are current developments going on in the country that point towards an increased interest in methane-driven heavy trucks.

A possible location for a biogas plant is between the municipalities of Värnamo and Gislaved, where there is a large potential of manure as well as a potential for using food waste. This could result in a production of approximately 20 GWh. The best option would be a wet co-digestion plant with a CSTR in mesophilic conditions.

Sammanfattning

Syftet med studien var att undersöka biogaspotentialen i Jönköpings län från både ett produktions- och marknadsperspektiv. Ytterligare ett syfte med studien var att förslå var en ny biogasanläggning skulle kunna byggas i Jönköping Region.

Studien genomfördes med hjälp av litteraturgenomgångar, kontakt med kommunerna och geografiska sökningar. För biogaspotentialen konstruerades två olika scenarier – ett realistiskt och ett utopiskt scenario. Marknaden undersöktes genom att observera användningen av fossil energi i regionen, framförallt med fokus på transportsektorn men delvis även industrier. En plan för en ny biogasproduktionsanläggning gjordes genom att undersöka tillgängligt substrat, var de fanns och genom att försöka hitta samband med nuvarande biogaslösningar eller gårdskluster.

I studien identifierades flera olika typer av substrat – gödsel, kommunalt matavfall, jordbruksavfall och avfallsströmmar från industrier (pappers och massa och livsmedelsindustrier). Störst potential kom från kogödsel som substrat, med en biogaspotential på 133–230 GWh/år i det realistiska scenariot och mellan 355–613 GWh/år i det utopiska scenariot. Den totala potentialen för regionen var 215–330 GWh/år i det realistiska scenariot och 460–740 för det utopiska scenariot.

För närvarande används majoriteten av biogasen som produceras i regionen för kollektivtrafik. Dock så används väldigt mycket större mängder fossila bränslen i transportsektorn än vad man hade kunnat substituera med biogas – även vid en utopisk utbyggnad av biogasproduktionen. Framförallt så används de fossila bränslena för bilar och tunga transporter. Det verkar finnas ett samband mellan antalet gasbilar och gastankställen, och det håller på att hända saker i Sverige som tyder på ett ökande intresse i metandrivna tunga lastbilar.

En tänkbar placering för en biogasanläggning är mellan kommunerna Värnamo och Gislaved, där det finns en stor potential från gödsel liksom en potential för att använda matavfall. Det hade kunnat resultera i en produktion av omkring 20 GWh. Det bästa alternativet hade varit en våt samrötningsanläggning med en CSTR som körs mesofilt.

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1. Introduction

The impact of climate change is a problem to be solved as the rise in global average temperature has and will continue to cause major environmental and economic effects unless the world manages to radically change its impact. Some actions have already been taken to reduce the impact on the climate. These include for example the adoption of international agreements for reduced climate impact, such as 21st Conference of the Parties (COP21), where governments of approximately 195 countries were urged to present proposals to reduce domestic emissions of greenhouse gases (GHG) aiming to limit the global temperature increase to 2 ˚C maximum until 2100 [1]. In Sweden, the target for the reduction of GHG emissions is, among other things, to become fossil fuel independent in the transport sector by 2030 (prop. 2008/09:93).

One kind of renewable energy that can be an important part in this, as it can be used as vehicle fuel in the transport sector, is biogas - a methane and carbon dioxide mixture that is a product from anaerobic digestion (AD). Anaerobic digestion is a biological process where organic matter, such as different kinds of organic residues or energy crops, is degraded in an anaerobic reaction performed by mixed colonies of microorganisms. The main outputs of AD are biogas, liquid effluent and digestate [2]. Biogas can be used for either directly for heat and/or electricity production, or it can be upgraded to biomethane through a separation of carbon dioxide [3]. The biomethane can then, for example, be used as vehicle fuel by compressing or liquefying it as it is then interchangeable with compressed natural gas or liquefied natural gas [3]. The digestate is rich in bioavailable nutrients, such as nitrogen, phosphorus and potassium, and can be used as a fertilizer for crops [4]. Digestate can also have the added benefit of making the nutrients more easily available for plants, than if for example manure would be used directly as fertilizer [5].

Sweden has for several years been a quite unique case regarding biogas use – in contrast to most other countries that use biogas for electricity or heat [3], Sweden used over 60 % of the biogas as vehicle fuel [6]. This large use of biogas as vehicle fuel is in large parts thanks to the Swedish regions – the number of gas cars is still small if the entire car fleet is considered [7], but the regions, who are responsible for the public transport in Sweden and have been key actors in the transition towards biogas in the bus fleet [8], have managed to make gas buses occupy over 16 % of all buses since 2014 [7]. Other public actors, such as municipalities, has also been key to the change towards biogas as several municipalities have used the public procurement process to buy gas vehicles – such as Jönköping, Värnamo, Nässjö and Gislaved [9]. Apart from being users of biogas, municipalities can also have other roles in the biogas system. In the first half of the 20th century, when the first anaerobic digestion plants were produced in Sweden [10], biogas was nothing but a by-product from wastewater treatment facilities [11]. Municipal wastewater treatment plants are still very important for biogas production, and produces 35 % of the yearly biogas production [6]. The municipals are also responsible for landfills and for the organic waste from households, which are other important substrates for biogas production in Sweden [6].

The region of Jönköping is one region in Sweden where there has been such a development towards biogas-fueled buses and gas-fueled publicly-owned vehicles. However, there is still a potential to increase both the production of biogas in the region as well as the use of biogas and digestate.

1.1 Aim of the study

The aim of this study is to make an estimation of the biogas potential in the region of Jönköping, both from a production perspective and from the market side. The purpose was also to propose a suggestion for a new biogas plant in the region, and to study the basis for implementation considering actors and drivers and barriers.

1.2 Scope

The aim of the study is addressed through studying the region of Jönköping and the different actors and characteristics therein that can be relevant for biogas through different documents, statistics and contacts. The focus was on creating an overview of the region rather than going into too much details regarding specific sites or actors, and the study ends up with six different sections – an overview of the potential for biogas production of biogas, a short discussion of digestate and its potential uses in the region, an overview of current and potential markets for biogas, an overview of important actors in the biogas system in the region of Jönköping, an outline of drivers and barriers for biogas solutions as well as a plan for a new biogas production plant.

The time perspective in the study is mostly focused on the current situation, i.e. the current amounts of inhabitants, manure, fuel use and so forth. Only smaller forays were done focusing more directly on the future, such as the potential to increase biogas used in buses during the coming decade or the chicken farm that has got permission to increase the number of animals.

2. Background

2.1 Jönköping County

Jönköping County (i.e. the region of Jönköping) is a land-locked region in southern Sweden, close to Vättern, that consists of 13 municipalities (Figure 1).

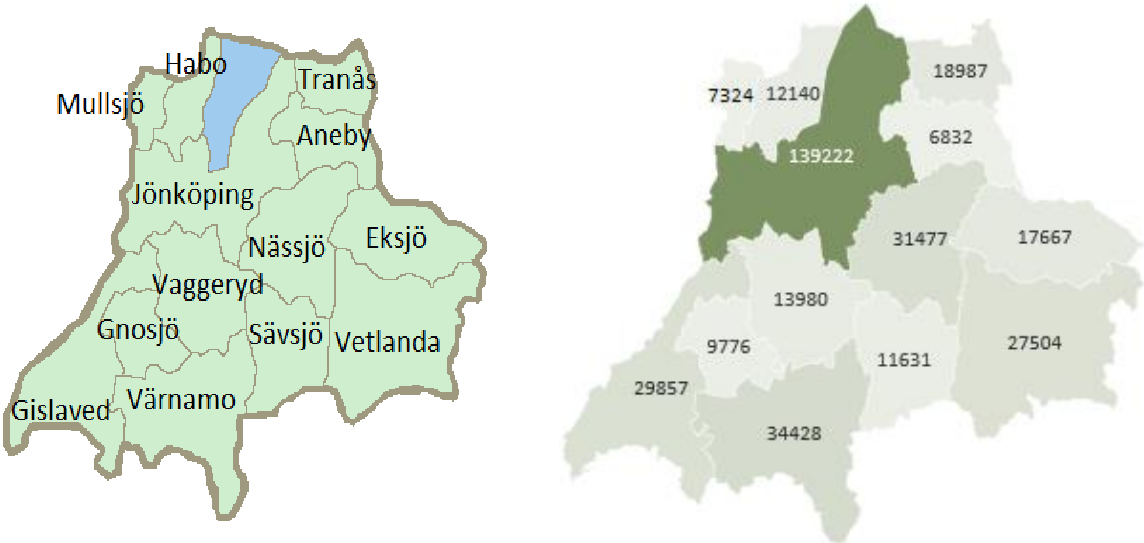

Figure 1. *A map of the region. To the left, the different municipalities are named. To the right, the population size of the municipalities are stated [12].*

Among these municipalities, Jönköping is the largest by far and is an important logistics hub with the E4 highway crossing it, as well as railroads and large roads to Gothenburg, Västervik, Borås, Trollhättan, Oskarshamn, Falköping, Mora and Halmstad. The area is mainly populated by smaller businesses and there is even something called "Gnosjöanda", that express small-scale entrepreneurship [13].

Almost 50 % of the GHG emissions in the region stem from transports [14] , likely due to the many large roads that cross the area as well as that it is an important logistic center. Among these transports, over 50 % are cars and around 20 % are heavy trucks [14]. Thus, around 25 % of all the GHG emissions in the region are due to cars. Apart from transports, about 25 % of the GHG emissions are from farms and there are also smaller emissions from heating, waste, industries, electricity production etc. [14].

2.2 Biogas in Jönköping County

Regarding the current production and use of biogas, the region of Jönköping is, in comparison to the rest of Sweden, one of the regions that produces smaller amounts of biogas (with 53 GWh in 2018 in comparison to the mean production of 97 GWh in the Swedish regions) [6]. If the population of the regions is considered, Jönköping is still in the lower part of the scale of biogas production (Figure 2).

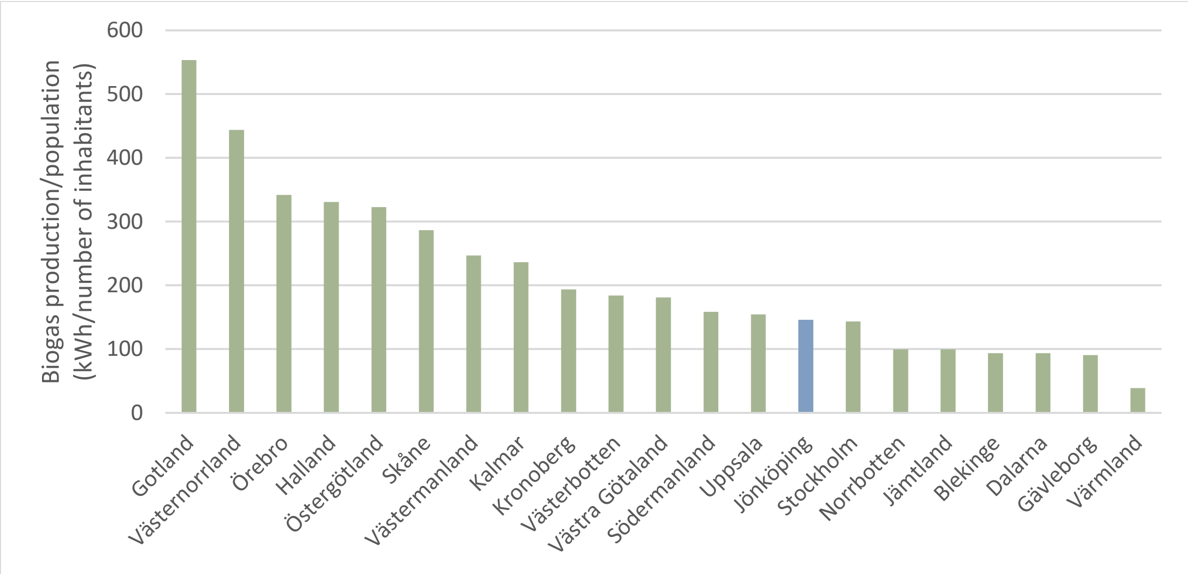

Figure 2. *The biogas production in the Swedish regions, divided on the population in each respective region (based on the data found in [6]).*

The production was done in 14 different plants throughout the region with a mix of wastewater treatment plants, farm scale plants, landfills and co-digestion (Figure 3). As of 2018 there were three plants which hade upgrading [6]. 45 GWh of biomethane was sold in the region in 2015, of which a large part of it (around 20 GWh) was used for public buses and service trips and another large part (around 20 GWh) was sold at refueling stations to private car owners and other vehicle users such as companies [9].

In January 2018 the municipalities in Jönköping County and Region Jönköping signed a Biogas Agreement to use as a guideline for biogas use and production in the county. This was written to try to make sure that there is a clear focus for the municipalities and region on how to promote biogas production and use [15].

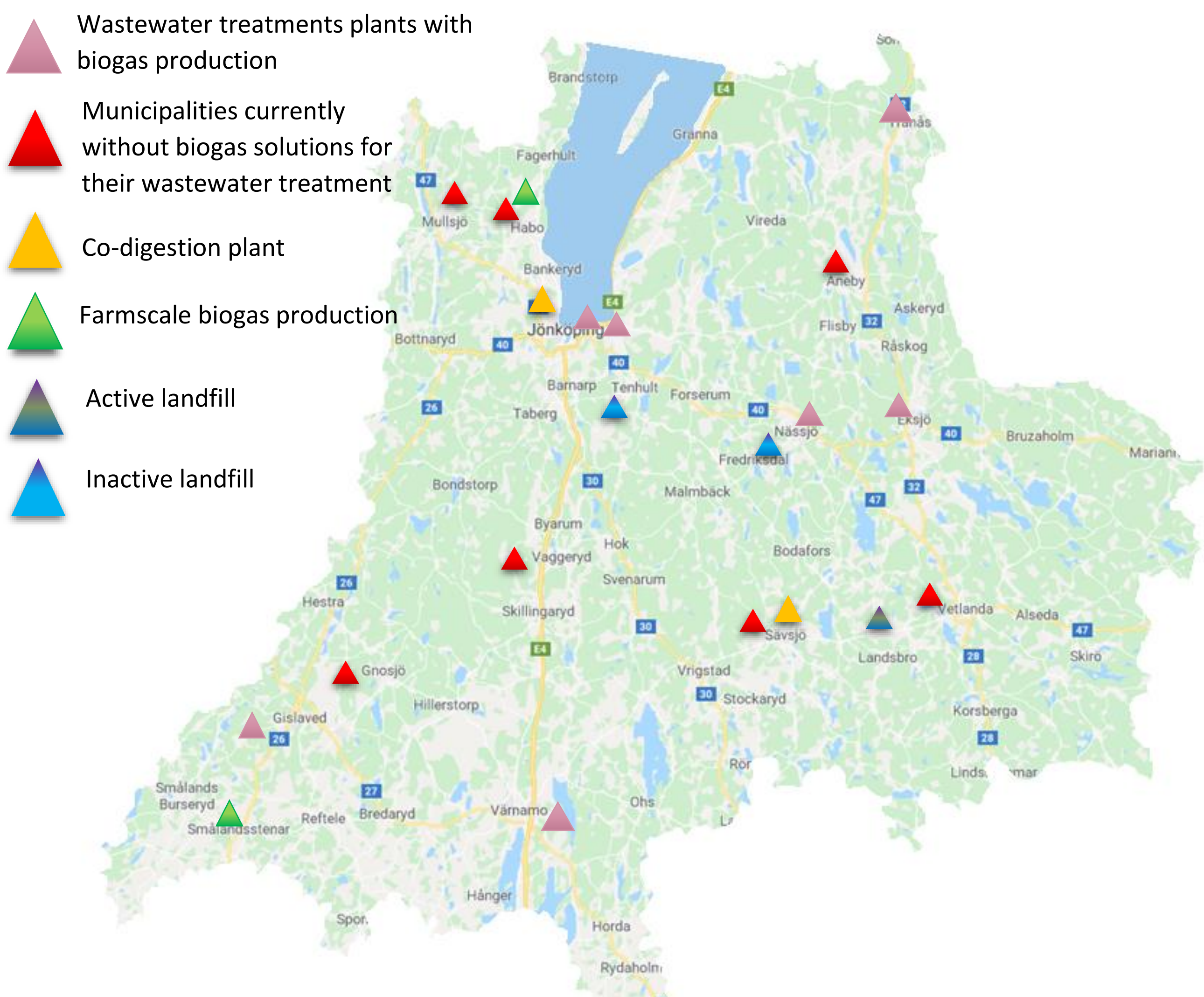

Figure 3. *A map of the current biogas plants in Jönköping based on type. The map also shows the municipalities which do not currently have biogas solutions for their wastewater treatment plant.*

2.3 Important parameters for substrates for biogas production

When choosing a good substrate some parameters need to be considered. One parameter is a good C/N ratio, an optimal substrate should have a ration between 15-25 as to not risk deficiency in either carbon or nitrogen [16]. A high nitrogen content may lead to inhibition as ammonia is formed as a degradation product and high concentrations can be toxic to the microorganism [16], [17]. To have enough trace elements in you substrate is also important as these are necessary for optimal enzyme activity an degradation [16]. Co-digestion and combinations of different waste streams is an option if you have “non-optimal” substrates from a C/N perspective or if you have low amounts of trace elements. From a large scale production point of view, important parameters like the total availability of the substrate and the possibility of transportation are important to take in to account [16].

3. Method

The study was primarily done based on document and literature reviews and using statistics from governmental organizations. Apart from that, information was gathered from the different municipalities regarding the manure in their municipality, and more extensive quantitative calculations were done for the potential substrates in the region. There were also several discussions with different actors active in the region, such as from Energikontor Norra Småland and JRC.

In order to study the potential of digestate use in the region, the arable land in the region was studied in regards of size, owning structure and soil structure based on governmental statistics and reports. This was then used in comparison with the benefits that digestate as fertilizer have.

For the estimations on current and potential use of biogas in Jönköpings County, different statistics from governmental organizations were mainly used to get statistics of for example fuel use, vehicles and the municipalities.

Regarding the Drivers and barriers chapter (chapter 8), the overview of the drivers and barriers was created in discussion between us authors, and the overview is thus primarily based on our previous knowledge of biogas and the biogas sector. Apart from the discussions, two previous studies that looked at drivers and barriers for biogas use were also used [3], [18].

3.1 Calculations of the potential for biogas production

3.1.1 Finding available substrates

To find substrates in the region, both a literature and geographical search was made for possible industries, farms and other activities that might generate streams of organic material usable for anaerobic digestion. Some possible substrates were mentioned in previous reports from investigations done in the region [19]. A literature search of scientific journals and doctoral theses, focused on previous studies of the substrates, was performed to confirm that the substrates were of interest. Aquatic biomass was disregarded as biomass for biogas production in Jönköping County since it is a landlocked region, and the potential from the lake Vättern was assumed to be very small.

3.1.2 Substrate and methane potential calculations

To do the calculation of methane potential, the amount of each available substrate needed to be estimated. This was done in slightly different ways depending on the substrate (see below for more specific explanations of how it was done, as well as in Chapter 4).

To get an estimation of the amount of biogas that could be produced, TS and VS values as well as methane potential test data (mainly based on BMP-tests) were acquired. TS and VS values were used to calculate how much organic matter is available, and methane potential test data is based on studies that look at how much methane can be produced from a certain substrate under optimal conditions. The used parameters can be found in *Table 1.*

To show the total estimations, two different scenarios were produced – one "Utopian" scenario that describes a best-case scenario, and a more "Realistic" scenario which assumes for example lower collection rates and adjusted methane potential test data. For the substrates that it was possible, each scenario also has a "high" and a "low" estimation, where the respective highest and lowest estimations for methane production were used.

The production acquired in m^3 of methane was then recalculated to GWh using that 1 m^3 of vehicle gas equals to 9,67 kWh [20]. For the full potential of the region, all individual numbers for substrates were combined in the different cases.

3.1.2.1 Municipal wastewaters

For the case of municipal wastewaters, the total amount of inhabitant in Jönköpings County was considered. Another thing that was considered was whether the municipalities already have biogas solutions for their wastewater treatment. The biogas production from another city's (Linköping) wastewater treatment was used as a reference to see what potential there is of producing biogas from wastewater sewage. The total amount of inhabitants in Linköping was then compared to the total amount of inhabitants in Jönköpings County. This was done in a similar fashion to what was done to estimate biogas production potential from wastewater in a previous investigation of the biogas potential in a municipality in Östergötland, where the future biogas production potential was estimated through an extrapolation of current biogas production and an increased population [21].

3.1.2.2 Manure

No regional or local estimations of manure amounts were found during the literature search. Instead, two own estimations were done in this study: by looking at the total amount of animals in the region, taken from Jordbruksverket's statistics on agriculture [22], and by looking at the farms in the region that have a larger number of animals, taken from the municipalities data on "anmälningspliktiga verksamheter".

When calculating the total potential for biogas production from manure in the region, this were based on the statistics from Jordbruksverket. The estimated amount of manure produced per animal per day or year was used, of which a total VS production per year was calculated. In the "Utopian" scenario, all the manure was assumed to be collected and the methane production was taken directly from the methane potential test data from lab-scale experiments described in scientific journals and reports. In the "Realistic" scenario, a manure collection of 50 % and methane yield of 75 % of methane potential test data was assumed based on Angelidaki et al. [23]. For the manure collection, the 50 % was used similarly to Cong et al. [24].

The manure amounts from "anmälningspliktiga verksamheter" were presented in order to see where the animals in the region are situated, approximations of how large the farms are, and for an estimation of how much biogas can be produced from manure from those farms. "Anmälningspliktiga verksamheter" means that any farm that have more than 100 animal units must tell the municipality how many animals they have or get a permission from the region if the farm has more than 400 animal units. These farms are in focus since biogas production requires a certain production size due to the investments, and smaller farms are likely not of any larger interest for situating biogas production. The animal units are based on estimated manure production, with 1 animal unit defined as for example 1 milking cow, 3 sows or 100 laying hens [25]. No farms with over 100 animal units of sheep were identified in the region.

3.1.2.3 Agricultural waste and ley crops

An overview of the amount of arable land in Jönköping County was made to estimate agricultural waste and ley crop production, as well as what type of crops were usually grown. This was made using different statistics from Jordbruksverket. From these results a discussion was formed analyzing if this type of agricultural waste was a good substrate to use for biogas production. No exact amounts of potential biogas production produced was calculated due to time limitations.

3.1.2.4 Municipal food waste

For the estimation of municipal food waste, numbers from a previous investigation of a potential biogas plant in Jönköpings County were used [19]. In that investigation, a low collection level was presented as well as a higher albeit realistic collection level. In the "Utopian" scenario, the total amount of organic waste produced per person and year was used to together with the number of inhabitants and methane potential lab data to estimate the total amount of VS for the region and the total methane potential from municipal food waste in the region. The "Realistic" scenario is completely based on the estimations done in a previous study in the region [19].

3.1.2.5 Waste from pulp and paper industries

To estimate the potential of biogas production from pulp and paper industries, data on waste streams, the amount of pulp or paper produced and process water used was collected from Skogsindustrierna's environmental database [26]. Information regarding the processes within the pulp and paper production plants were also collected through this database, as well as from the companies' websites.

An estimation of the biogas potential per tonnes produced pulp was found from literature, and this was directly applied on the process for Waggeryd Cell. However, full details of the production processes regarding Munksjö Paper AB were not found except how much paper they produce. In that case, the total production of paper was compared to another plant which also only produce paper and no pulp. The total amount of process water was also compared between the two plants to give an estimation of the potential from that data.

3.1.2.6 Industrial food waste production

According to a presentation of the region from Energikontor Norra Småland [14], there are no large scale industrial food production in the region. There are, however, smaller industries within the region. Two of these are mentioned later in this study, but biogas production potential was not calculated for any of them. Instead, a discussion was made about the feasibility of the waste streams in a biogas process based on previous literature and information from other biogas processes.

Table 1. Parameters used in the calculations

Substrate	Amount of animals/ people	Total Amount	Unit	TS (%)	VS (% of TS)	Methane potential test data	Comment
Cattle manure	128 534 [22]	5.5-7.3 [27]	kg DM/animal and day	-	81 [28]	216-292 m^3/tonnes VS [29]	
Sheep manure	32 082 [22]	0.5 [30]	kg/animal and day	25 [30]	85 [30]	150 m^3/tonnes VS [31]	
Pigs manure	7 150 [22]	1.9-8.4 [32]	kg/animal and day	16 [31]	92 [31]	444 m^3/tonnes VS [31]	
Chicken manure	68 025 [22]	65 [33]	Tonnes / 1000 animals and year	33[34]	77 [34]	173 m^3/tonnes VS [31]	
Liquid manure	-	50000 [19]	m3/year	-	-	24 m^3 biogas/tonnes WW [19]	
Wastewater treatment plants	360 825 (total) 61 683 (without biogas solutions) [12]		-	-	-	20 GWH produced in Linköping [35] (population 161 371) [12]	
Municipal solid waste (food waste)	360 825 [12]	47-60, 97 [19]	kg/person/year	28 %	88 %	400- 600 [16]	
Wastewater from Waggeryd cell	-	166 000 [36]-175 000 [37]	Tonnes of pulp produced	-	-	0.13 MWh/tonnes produced pulp [38]	
Wastewater from Munksjö Paper AB	-	15 000 [39] 2 [39]	Tonnes of paper Million m^3 of process water				
Agricultural waste	-	80 000 [40] 75 [40]	Hectares of arable land, % of arable land used for ley	-	-		
Waste from candy production in Gränna	1 100 [41]	Tonnes of candy produced per year					Could be possible extra addition to co-digestion process
Cleaning waters from Arla	200 million liters of raw milk each year [42]						Not intended to be used as sole substrate but to dilute

4. Potential for production of biogas

Several types of substrates for anaerobic digestion can be found in Jönköping County. As previously described, the substrates will be estimated for two scenarios – a “Utopian” scenario and a “Realistic” scenario. The substrates will also be estimated for “high” and “low” values, in order to better see the spectrum in which the reality may lie. All values used in the calculations can be found in Table 1.

4.1 Municipal wastewater

Currently the following municipalities in Jönköpings County do not have biogas production connected to wastewater treatment: Vetlanda, Vaggeryd, Habo, Sävsjö, Gnosjö, Mullsjö and Aneby. These cities have a total population of 61 683 people [12]. Making a comparison with the biogas production from the biogas plant in Linköping which is run on municipal wastewater and produces 20 GWh per year [35] gives a potential of a total production of 25 GWh for the total population in Jönköpings County in a case were all municipalities have biogas solutions connected to their wastewater treatment. A previous study of the potential of municipal wastewaters showed a potential of 27 GWh in Jönköping county by Linné et al. [43], which is not far from the estimation made in this report. In this case they have split the different cities in population groups to perhaps give a more representative potential in relation to the amount of substrate in each city.

In the case of Sävsjö, which is one of the municipalities that currently does not have biogas solutions for their wastewater treatment, there is a co-digestion plant in the municipality. This co-digestion plant is currently upgrading their biogas, and a possibility for the future is to use this upgrading facility for a future biogas plant that also run on municipal wastewater. In the case of Vaggeryd, the production might be combined with potential anaerobic treatment of Waggeryd Cells waste streams and thereby also being able to combine the upgrading for two plants. In Jönköping region some of the cities are smaller in size so the economic feasibility for applying biogas solutions might not optimal. However, in previously mentioned study by Linné et al. [43], the possibility of moving sludge from smaller treatment plants to larger with AD treatment was discussed. Which could enable higher use of sewage sludge for anaerobic digestion.

4.2 Manure

Another potential substrate for biogas production is manure, both in liquid and solid phases. Almost all the agricultural land in the region is used for animal husbandry [40]. Looking at the total number of animals in the region in 2017, cattle was identified as the most common (129 000), followed by chicken and hens (68 000), sheep (32 000) and finally pigs (7 000) [22]. However, using manure from small-scale farms for biogas production can be difficult, and only a very small part of these animals is based on larger farms. As can be seen in Figure 4, there are for example no large farms with sheep, and a few larger farms with pigs and chickens.

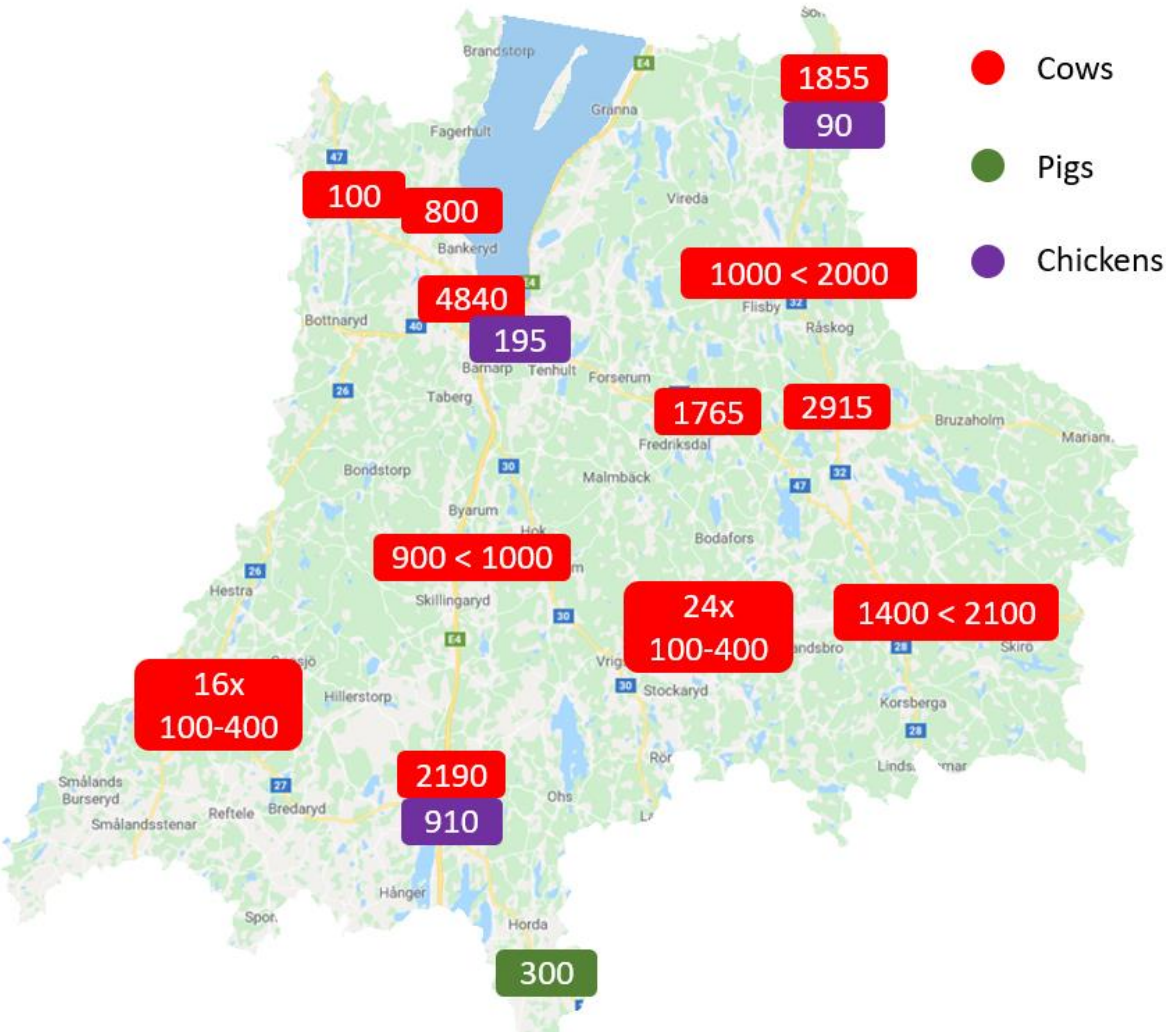

Figure 4. The number of animals, counted in animal units according to Jordbruksverket's regulations, that are situated in farms with over 100 animal units.

4.2.1 Potential from cow manure

There were 129 000 cattle (dairy cows, breeding cows, calves, bulls and heifers) in Jönköping County in 2017, which is around 1/10 of all the cattle in Sweden [22]. From this it can be concluded that that manure from cows is a potential substrate to consider in the biogas potential for the region. However, of the cattle in the region, around 40 000 is calves [22]. Calves produce considerably less manure compared to a dairy cow, which was taken into consideration in the calculations – an estimation was made that the calves produced around 1/6 of the manure compared to full grown cows [25].

The C/N ratio of liquid manure from cattle ranges somewhere between 6-20 [16], where a desirable substrate should have ratio between 15-25 [16] which might make it a suitable substrate for digestion on its own but will probably give a higher biogas production when co-digested with a substrate with a higher C/N-ratio.

For the utopian scenario, all manure was assumed to be collected. A full-grown cow produces 5.5 kg [27] of dry matter which resulted in an estimation of a methane potential of 354.9 GWh/year. For the higher case of the utopian scenario, a higher yield was considered with 7.3 kg of dry matter per day and cow [27] - resulting in 612.7 GWh methane/year in the region. For the realistic case, 50 % of the manure was estimated to be collectible and 75 % of the methane potential test data was estimated to be acquired. According to this, the biogas potential for cow manure would be between 133.0-229.8 GWh/year. Looking at Figure 4, several clusters of farms with cows can be observed.

In the discussion regarding a potential plant in Reftele, specifically liquid manure was mentioned as a possible substrate to use [19]. The quantities mentioned there were around 50 000 m3/year. All liquid manure would be collected from farms within 10 km of the future plant. Due to the proximity of the farms to potential plant this is a case which is very close to be realizable. In the report, 24 m^3 of biogas (methane concentration of 65 %) per tonnes liquid manure was estimated. This would lead to a potential of 7.5 GWh per year.

4.2.2 Potential from sheep manure

In the region of Jönköping, there were 32 000 sheep and lambs in 2017 [22]. Approximately half of these were fully-grown sheep (15 000) and half were lambs (17 000), and among the fully-grown sheep less than half is in herds with more than 49 sheep [22]. The estimation of the potential was 0.55 GWh in the realistic scenario while in the potential could reach 1.82 GWh in the utopian scenario. Although there are farms with large amounts of sheep, such as Erikshester gård close to Vetlanda with 500 sheep [44], the manure amounts are still small enough that they are not “anmälningspliktiga” (since 500 fully-grown sheep corresponds to only 50 milking cows). However, if there are other potentials to produce biogas in the nearby area, there might be potential to co-digest the sheep manure.

4.2.3 Potential from chicken manure

The number of chickens and hens in Jönköping County was 68 000 in 2017 [22]. One of the farms, in Värnamo, has gotten permission to increase their amount of chickens from around 30 000 to 90 000 chickens [45]. There is thus a possibility that the potential from chicken manure will increase in the future. However, there are only six farms in the region which are in a larger scale. When looking at Figure 4, it is possible to see that these farms are situated primarily close to Jönköping and Värnamo.

Chicken manure generally has a higher protein content compared to e.g. cow manure and food waste [16], making it an alternative for co-digestion with materials that have a higher C/N ratio. For the realistic scenario, the potential is 0.7 GWh methane per year, while the utopian scenario, where all the manure could be collected, would have a higher potential of 1.9 GWh. As can be seen, the potential from the chicken manure is not that large but can be seen as co-substrate to larger fractions of substrate e.g. cow manure or food waste.

In the case of chicken manure, there were limitations in the data found on how much chicken manure is produced from each chicken, thus there is no range of the potential and the estimation is the same for both the high and low values for both scenarios.

4.2.4 Potential from swine manure

The total number of swine in Jönköping County was 7 000 in 2017 – primarily smaller pigs, with only less than 1,000 sows and boars [22] - and there is only one large farm (Figure 4). Looking at statistics in Sweden, Jönköping County is one of the smallest producers when it comes to swine, only Västernorrland has fewer swine, and it might thus not be the most obvious target group for substrate collection. However, the methane potential per tonnes VS of substrate is higher than for example cow manure (around 440 Nm3/tonnes VS [31] compared to 200-300 Nm3/tonnes V [29], [46]) which still make it viable as a substrate if you can find farms with a large quantity of animals and are situated in a good position in relation to other substrates. Swine manure is also more protein rich (similarly to chicken manure) [16] which can make it a possible co-digestion substrate in processes deficient in nitrogen. When looking at the realistic scenario, the potential for swine manure is between 1.2-5.2 GWh per year. In the case were all manure could be collected and a higher methane yield, i.e. the utopian scenario, the potential is between 3.2-14 GWh.

4.2.5 Potential from manure from identified "anmälningspliktiga" farms

To finish up the text about the manure, a calculation based on the farms which are "anmälningspliktiga" in each municipality should be done. The previous calculations are done on the total amount of animals in the region, but it is difficult for smaller farms to use biogas solutions. To study the "anmälningspliktiga verksamheter" is instead a way to see what potential for biogas production there is from manure from larger farms. As these farms have a larger number of animals, they are more likely to be the focus for potential biogas plants. The total amount of animals and farms can be found on Appendix 1. The number of animals is presented in a range so the cases discussed here will be presented as a range based on the highest and lowest number of animals. In the case of sheep, there were no farms in the region of this size.

The calculation gave a total amount of 16 400-30 900 cows, 70 000-120 000 chickens and 1 500-2 000 pigs. As can be seen, the amount of chicken is very close or even higher than the total number of chickens found from the statistics in Jordbruksverket – which is a discrepancy since there should be many more chickens than only the ones situated at large farms. Chickens are a popular animal for hobby farms, and it is not uncommon for people living in the countryside to have a small number of chickens. This discrepancy likely originates from that you have to report to Jordbruksverket directly as soon as you have 1 sheep, 1 pig or 1 cow – but for chickens, you only have to report to Jordbruksverket if you keep chickens for commercial purposes or if you have more than 350 laying hens [47].

In this calculation, the results are also presented as two scenarios: "utopian", where the estimated total potential of manure is calculated, and "realistic", where 50 % collection was done, and 75 % methane production achieved compared to the methane potential test data. The results can be seen in Table 2. The highest potential is still from cow manure, in the utopian scenario between 55.7-188.3 GWh/year, while the methane production potential for chicken and swine manure was somewhere between 0.2 and 4 respectively for each possible scenario.

Table 2. *Presentation of the methane potential from manure based on the "anmälningspliktiga" farms in the different municipalities.*

Scenario	Explanation	Cow (GWh)	Chicken (GWh)	Swine (GWh)
Utopian	Total collection and methane production	55.7<188.3	1.93<3.32	0.67<3.87
Realistic	50 % collection, 75 % methane production	20.9<70.6	0.72<1.24	0.25<1.45

4.3 Agricultural waste and ley crops

The biogas potential from agricultural waste and ley crops is also something to be considered. Especially the use of ley has been discussed for biogas production as it binds both nitrogen and carbon, which improves the nitrogen content in the digestate and a return of carbon to the soil [16].

The amount of arable land in Jönköping County is not large in comparison to e.g. Skåne, Östergötland and Västergötland, and the agricultural land in the region is split between 80 000 ha of arable land and 40 000 ha of pastures [40]. Among the arable land, around 75 % is also used for ley crops (Figure 5), and 80 % of the agricultural land is thus used in some way as animal fodder – as pastures or for growing fodder. However, there is a potential that not all ley is used as fodder and could instead be used for biogas production. Based on the data acquired it is hard to make an estimation on what the potential would be. More research must be done to get a proper estimation how much of ley that is currently used as fodder and how much has a potential as a biogas substrate. However, in the investigation for a potential biogas plant in Reftele [19], crops, grains and ley were not considered a profitable substrate due to EU regulation regarding energy crops for biogas production.

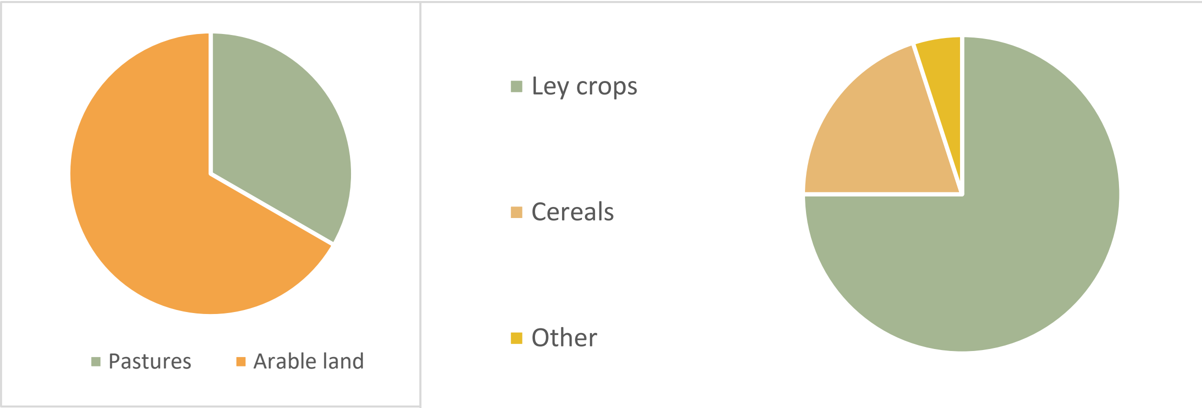

Figure 5. Distribution of agricultural land in Jönköping region as of 2017 and the distribution of crops on the arable land. Figures adapted from data from Jordbruksverket [40].

4.4 Potential from food waste

Currently there are two biogas plants in Jönköpings County which digest food waste: a co-digestion plant in Jönköping and a co-digestion plant in Sävsjö.

The municipalities Gislaved, Värnamo, Vaggeryd and Gnosjö have started a plan for collecting food waste in their municipalities. The waste can then be used in a possible biogas plant that might be built in the nearby area (specifically in Reftele) [19]. In the report, in which the plant was discussed, a food waste potential between 4 070 – 5 210 tonnes/year was calculated for the four municipalities. The lower value represent a lower collection ratio while the higher value represent a higher, but still realistic, collection ratio [19]. The values are based on estimations of 47 kg/person and year (the lower estimation) and 60 kg/person and year (the higher estimation). If the same estimation is done on the entire population in the region, for the utopian scenario, the estimated collected food waste would be 17 801 < 20 117 tonnes (based on 360 825 inhabitants). This could lead to a potential biogas production of 16-28 GWh methane/year in Jönköping County. All these calculations are based on a methane potential test data of 400-600 m^3 methane/tonnes VS [16].

4.5 Potential from pulp and paper industries

In Jönköpings County, two pulp and paper industries have been identified: Munksjö Paper AB in Jönköping and Waggeryd Cell AB in Vaggeryd municipality [48]. The potential of treating waste streams from the pulp and paper industry with AD is something that has been discussed by Ekstrand [49] and Larsson [50] etc. The wastewater treatment has been identified as one of the bottlenecks for the production of pulp and paper and treating the waste treatment streams might be able to increase the production [50].

4.5.1 Waggeryd Cell

Waggeryd Cell AB has a chemical thermo-mechanical (CTMP) process [51] focused on producing pulp [37]. They produce 166 000 tonnes of bleached pulp in 2017 [51] (total production capacity of 175 000 tonnes), and after production the majority of the pulp is exported [37]. In previous studies, the CTMP process has been found to have some waste streams, such as pulp and bleach streams, which have promising potentials for methane production [52]. The biogas potential from CTMP mills have been estimated to 0.13 MWh/ton produced pulp [38]. Using this information and knowing the production of Waggeryd Cell (166 000 tonnes in 2017 and total possible production 175 000 tonnes) we get potential biogas production between 21.6 to 22.8 GWh per year.

4.5.2 Munksjö Paper AB

Munksjö Paper AB (owned by Ahlstrom-Munksjö) situated in Jönköping city does not seem to have production of pulp, only direct production of paper and cardboard in a total 15 000 tonnes per year [39]. This is not the largest production when comparing to e.g. Fiskeby outside of Norrköping (a pulp paper mill with biogas solutions) which has a total production of 169 000 tonnes of paper in 2017 [53]. The pulp used in the paper production in Jönköping is made in Ahlstrom-Munksjö's other plants and is then delivered to Jönköping for the production of primarily electrotechnical paper [54], [55]. Some possible waste streams form paper production is white water from the paper- and drying machines. The waste streams from only paper production streams have shown to have lower amounts of organic matter compared to for the pulping streams e.g. from a CTMP process (0.1-0.5 tonnes TOC/m^3 compared to 1.5-2.9 tonnes TOC/m^3) [52]. However, laboratory methane potential tests showed that that paper- and drying machine white waters still had a methane potential of 500 – 600 m^3 methane/tonnes TOC (total organic carbon) from some of the investigated plants in Ekstrand et al [52]. Depending how large these waste streams are there is a potential for biogas production from these.

4.6 Industrial food wastes

The dairy industry in Jönköping, owned by Arla, is among the largest food industries in the region [56], and large parts of the agricultural land is used for milking cows. Apart from the dairy, there are also a large number of other food industries in the region, although the majority of them are in a smaller scale [56]. According to the regional food strategy [56], there are approximately 30 larger industries for food processing (primarily meat processing). There have, however, been difficulties in finding more information about these industries since there is no statistics or other kind of overall information that can be found of them due to secrecy issues. As such, only one food-processing industry was chosen for further study – Gränna candy production. Apart from being open enough with their data to enable calculations, candy production also produces waste that has previously been used successfully for co-digestion in the region [57].

There are three slaughterhouses in the region [56] (previously four, one was bankrupted in 2019 [58]). However, none of them appears to be large-scaled industries e.g. [59]–[61]). Instead, the regional food strategy points out that the region is close to several slaughterhouses, such as the large slaughterhouses in Västra Götaland County [56]. Slaughterhouse wastes was thus not considered to have a large enough potential to warrant specific calculations, but it might be of interest for co-digestion if there are biogas production plants in the nearby area with the right pre-treatment.

4.6.1 Arla dairy industry

Arla (Jönköping mejeri) receives 200 million liters of raw milk each year [42]. To discuss the potential from Arla, the similarly sized plant in Linköping can be taken as an example. The cleaning water from Arla's process in Linköping has been used to dilute the substrate in a co-digestion plant in Linköping. The plant of Arla in Linköping receives 220 million liters of raw milk each year [62] making it similar in size to that in Jönköping. The amount of cleaning water that the Linköping biogas plant receives was confidential and the only information acquired was that in Linköping they do not only use the cleaning water [Anonymous, 2019] as a dilution source for the process. This option of using cleaning water for co-digestion is an option that could be considered for upcoming biogas production plants close to Jönköping, if they will need to dilute the material. Wastewater streams from dairy plants usually have waste streams that contain, fat, proteins and sugar, which can contribute to increased methane production in the process and not only a tool for dilution [63].

4.6.2 Candy production (Gränna)

Gränna is a town famous for candy cane and candy production in Jönköping County. We could not find any source that presented all the candy waste in the town that could be used, and instead focused on only one company - Franssons konfektyrer. Franssons konfektyrer is a candy company in Gränna that produces 1 100 tonnes of candy each year [41]. The amount of substrate produced is not enough to run a process on, but it could be added in a co-digestion process. This was discussed as an option by Kaparaju et al. [64] in relation to a continuous process that ran on cow manure where the addition of candy by-products increased the specific methane yield from 0,22 m^3 /kg VS to 0,28 m^3/kg VS. By-products from candy production has also been previously for biogas production in Jönköping County together with used manure [57]. As Jönköping County have large amounts of manure, this could be a possibility to boost the production at times.

4.7 Total potential for biogas production and enabling of this production

The total biogas production in Jönköpings County 53 GWh (including biogas production from landfills) as of 2018 [6]. The total amount of energy that can be acquired from the biogas production has been estimated from the assumption of an upgraded biogas with 97 % methane, where 1 Nm^3 equals 9.67 kWh/m^3 [20]. Adding all the potentials for biogas production that has previously been listed for each substrate gives a total potential in the region of between 215-330 GWh in the realistic scenario and between 460-740 GWh for the utopian scenario (see figure 5 and 6 as well as Appendix 2). In the realistic scenario, a 3<5-folded increase of the current production could be achieved. In the utopian scenario, it is possible to achieve a 12-fold increase of biogas production. However, the utopian scenario is likely impossible to achieve in practice since the values imply that all the manure in the region is collected.

To increase the biogas production, it is not always necessary to build new plants – in some cases, the biogas production plants that already exist could be used more efficiently. For example, Sävsjö. The co-digestion plant in Sävsjö has a yearly production of around 11 GWh at the moment, but their owners Biond mentions that they actually have a capacity of 40 GWh [65]. There can also be possibilities of expanding the biogas production in wastewater treatment plants that currently have biogas solutions. Westerholm [66] discusses thermal pre-treatment as a possibility to run a process of wastewater sludge and household waste at a higher loading rate, but concluded in the article that it was possible to run the process at a higher organic loading rate even without the heat-treatment. This shows that, in some cases, it might be possible to increase the organic loading rate in existing processes and thus get more biogas without big investments in new plants.

There is also the potential to start producing biogas from wastewater treatment plants that do not have any biogas solution now. Potential new biogas production plants related to wastewater treatment could also be combined with other biogas processes. For example, Vaggeryd is one of the municipalities that does not have any biogas solution for their wastewater treatment plant, and there is also a pulp plant in Vaggeryd (Waggeryd Cell) that has potential substrate that could be combined with biogas production from the municipal waste water sludge.

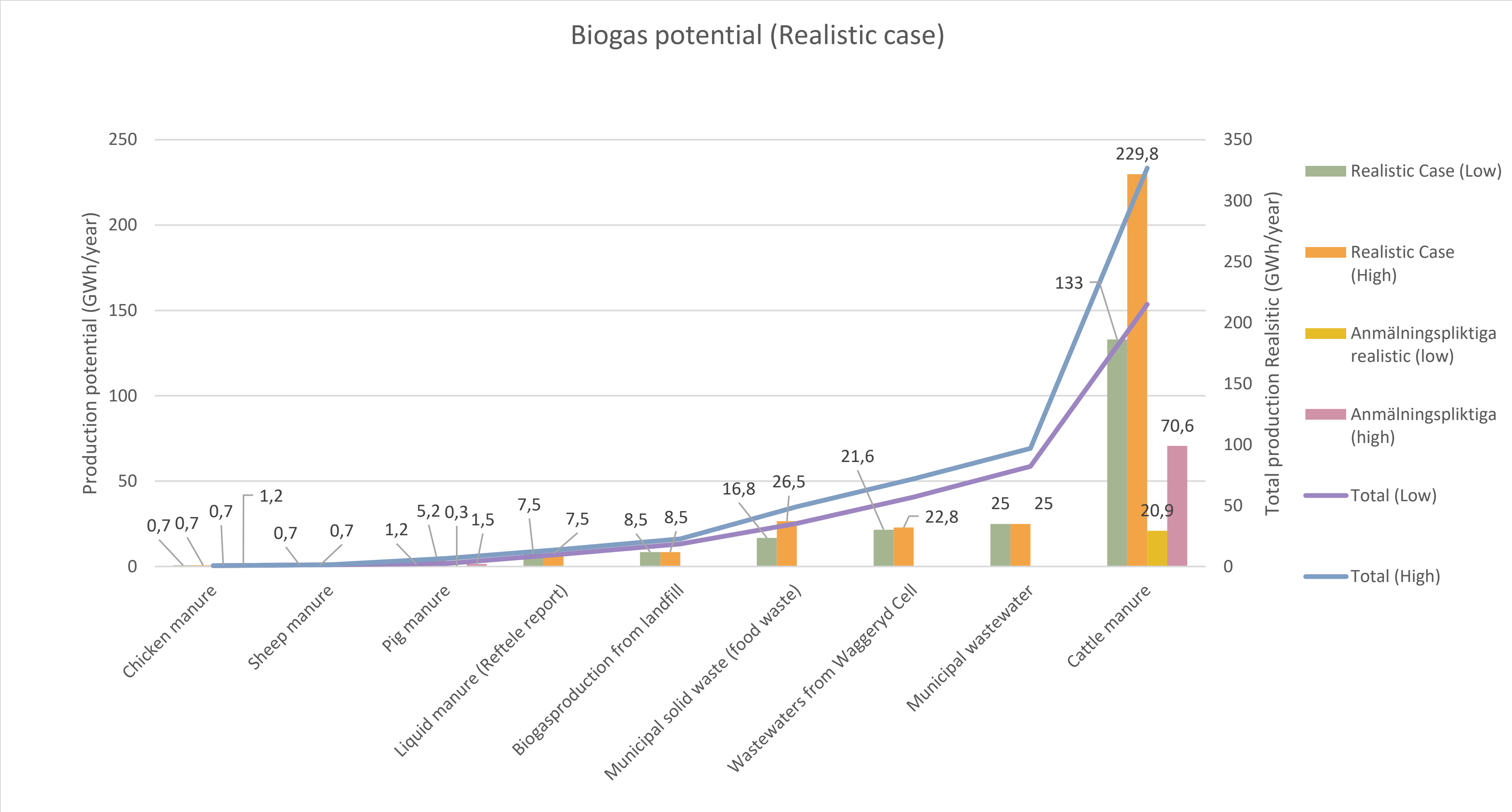

Figure 6. *The biogas potential in Jönköpings County based on the identified substrates (realistic scenario, 50 % collection rate and 75 % methane potential for the case of manure and 47-60 kg/person and year for the food waste scenario).*

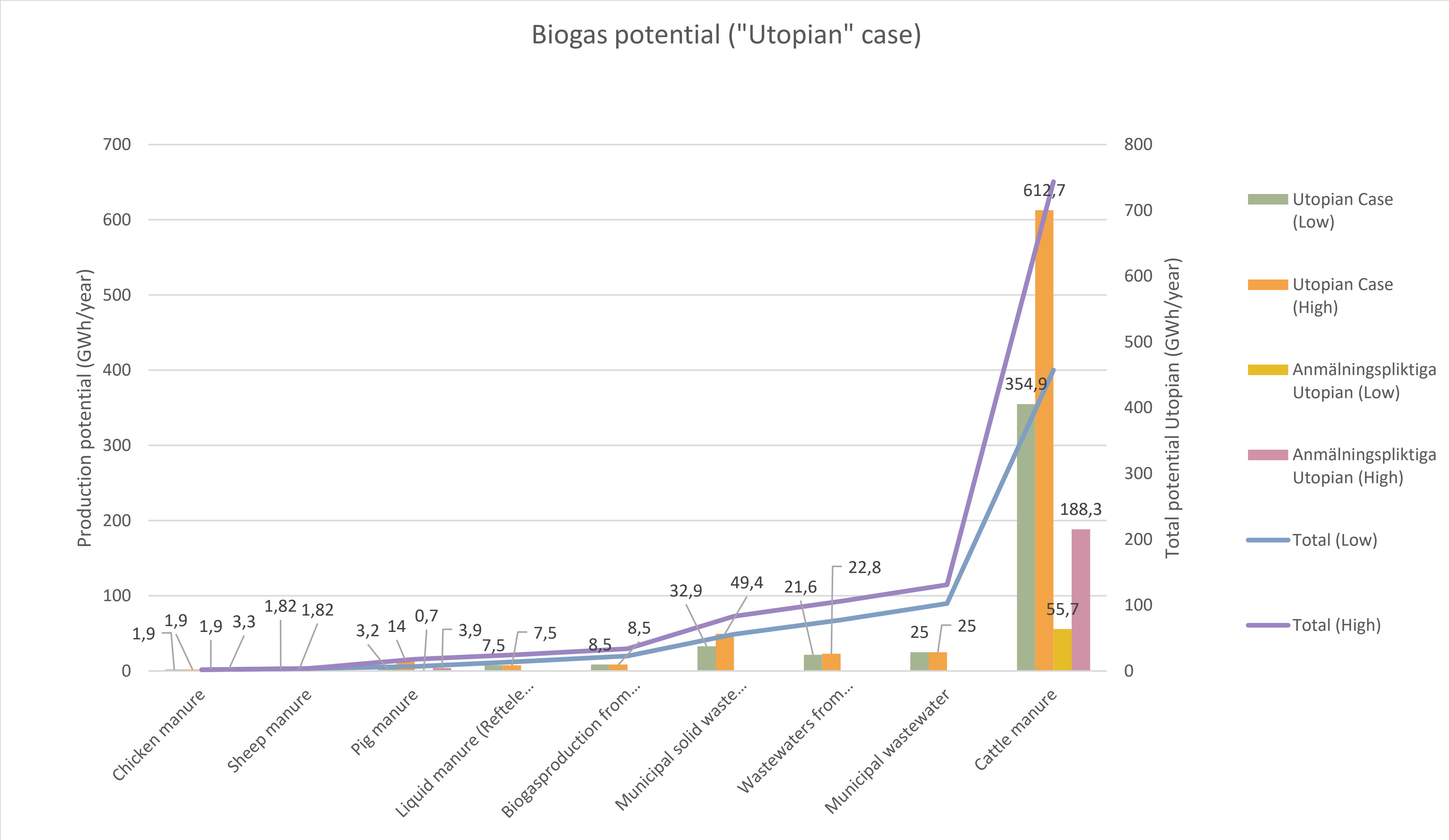

Figure 7. *The biogas potential in Jönköpings County based on the identified substrates (utopian scenario).*

As can be seen in Figure 6 and 7, manure constitutes a large part of the potential substrate in the region. One of the major problem areas when using manure is the transportation of the substrates, especially liquid manure can be problematic to transport longer distances as the TS-content is quite low and you are mostly transporting water. However, since it is mostly liquid it is pumpable for shorter distances. In the case with manure, it is important to place the plant so that as many farms as possible have a short distance to transport their manure. Especially since the farms are also the ones that afterwards will use the digestate as fertilizer. If one uses more solid manure fractions such as chicken manure, these could perhaps be transported a slightly longer range. Substrates such as food waste are also possible to economically transport longer distances.

Currently, farm scale plants in Sweden are usually in a smaller-scale [67] and only produces 3 % of the total biogas production in Sweden [6]. Of this gas, only 32 % of the gas is upgraded to vehicle fuel [6]. Looking at the statistics for biogas production plants in Sweden, almost all the largest plants are upgrading much of their biogas to biomethane while smaller plants, especially plants with a lower annual production than 3 GWh, almost never upgrade the biogas but instead uses it for primarily heat [3]. However, using biogas for heat or electricity is not the most economical solution in Sweden, even though it requires less investments than upgrading [3]. Manure and other agricultural feedstock can also be used in co-digestion plants, which is often seen in Sweden today, which often have a larger production scale than only farm-based plants and which are more often upgrades the gas to biomethane [67]. An important thing to consider is thus to, in some way, coordinate different substrate streams to increase the production size, either by moving the substrate or by moving the biogas before it is upgraded.

An example of such a kind of coordinated effort is the case of Brålanda Biogas AB, where farmers have gone together with the local municipalities and built a local gas grid for raw gas, an upgrading plant and a tank spot for fuel gas [68]. Another example is Alvesta biogas, where 12 farmers have gone together and made a profitable biogas plant by combining manure from their farms with slaughterhouse waste [69]. Hagelsrums biogas is also a smaller scale plant, which has been able to expand their activity by support from Klimatklivet which enables them to build another digester and a fueling stations [70]. In this case the municipality has also played an important role as it have decided that it will start to use biogas cars in its car fleet and that the collected food waste will now go to Hagelsrum instead of other larger plants.

When looking at the possibility to increase the biogas production from food waste, the Biogas Agreement for the municipalities and the region will be a great enabler for substrate collection as this is one of the agreements [15] that the municipalities shall work for. Another factor that will most likely drive the collection of food waste and make cases such as the ones presented above realizable is demand on municipalities to have a separate collection of food waste [71]. Increased collection of food waste in the municipalities can also enable the possibilities of using more manure as substrate as this can push the production and enable investments in upgrading plants.

5. Digestate

5.1 Arable land in the region

Looking at the market for digestate, Region Jönköping is not one of the most farming-intense regions in the country and use 8 % (around 80 000 hectares) as arable land and 3 % (around 40 000 hectares) as pastures [22]. In comparison, 40 % of the land in Skåne is used as arable land and the arable land in Södermanland, Östergötland and Västra Götaland are around 20 % [22].

Most of the farms in Jönköping County are smaller, with between 0-50 hectares, but there are also several middle-sized farms at 50-200 hectares (Figure 8). However, in contrast with many other regions in the country, there are almost no large farms with more than 200 hectare of arable land [22]. The bigger farms in the region are mainly situated in the northern part, in Jönköping, Tranås, Mullsjö and Habo [40].

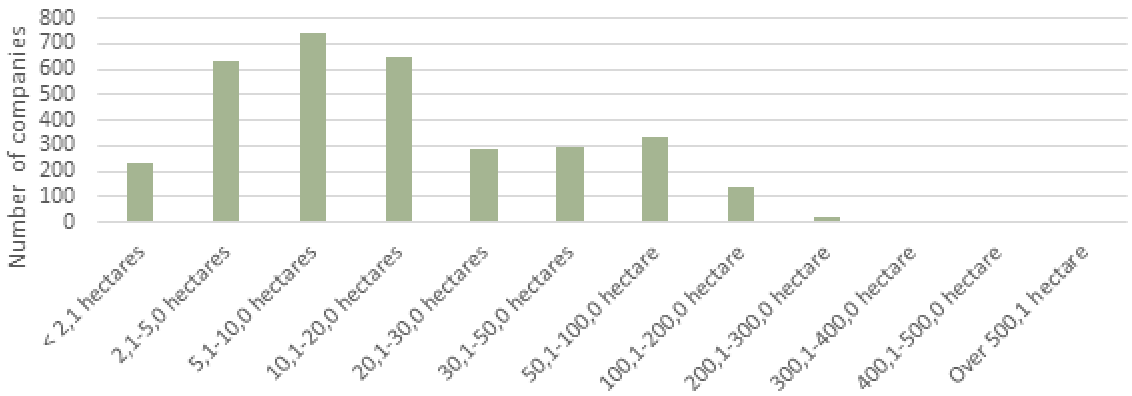

Figure 8. *The size of arable land for each farm in Region Jönköping [22]*

Generally speaking, the land has a large content of sand in the soil (>50 %) and lower contents of clay (0<15 %) and silt (7<40 %) [72]. The humus content in the region is shifting, with between 3 and 10 %, and the pH is between 5.6-6.2, which is lower than in the more farming-intense regions [72]. The phosphorous saturation is low in the entire region, with around 2-26 %, and the phosphorous binding capacity is high [72]. The easily soluble potassium is also on the lower part of the scale in the region of Jönköping, with mainly 0-8 mg/100g [72]. Regarding nitrogen, especially the western part of the region is part of a leakage region that in a study from 2008 was found to have a quite high leakage of nitrogen – not at the level of Skåne and Halland but on the higher part of the scale [73].

5.2 Digestate as fertilizer

Digesting the organic material, for example manure, increases the short-term N fertilization effect and improves flow properties [74]. As such, it can allow for a more accurate dosage [74] and decrease the risks of eutrophication. For animal farmers in the region, it could thus be of interest to use anaerobic digestion of their manure in order to decrease the nitrogen runoff when using the manure as fertilizers – which, according to a study in 2008 [73], seems to be a problem.

Apart from the use as fertilizers, the digestion process also reduces the odors [74], and companies that have organic waste material that has large problems with odor can thus decrease the problem by having it digested. For example, the chicken farmer in Värnamo that is planning to expand his business has to keep all the liquid manure completely covered to decrease the risk of odor problems [45].

6. Current and potential markets for biogas

Jönköpings County is an important logistic hub, with the E4 highway crossing it as well as railroads and large roads to Gothenburg, Västervik, Borås, Trollhättan, Oskarshamn, Falköping, Mora and Halmstad. In 2016, almost 50 % of the greenhouse gas emissions in the region came from transports, where more than half came from cars and a large part of the rest came from heavy trucks.

Jönköpings County is one of the few regions in Sweden that is connected to the international gas grid, via the municipalities of Gnosjö and Gislaved. There is one public refueling station for CBG each in those two municipalities (Figure 9). Apart from that, there are also refueling stations for CBG in Jönköping, Nässjö, Sävsjö and Värnamo, as well as two public refueling stations for LBG in or nearby Jönköping.

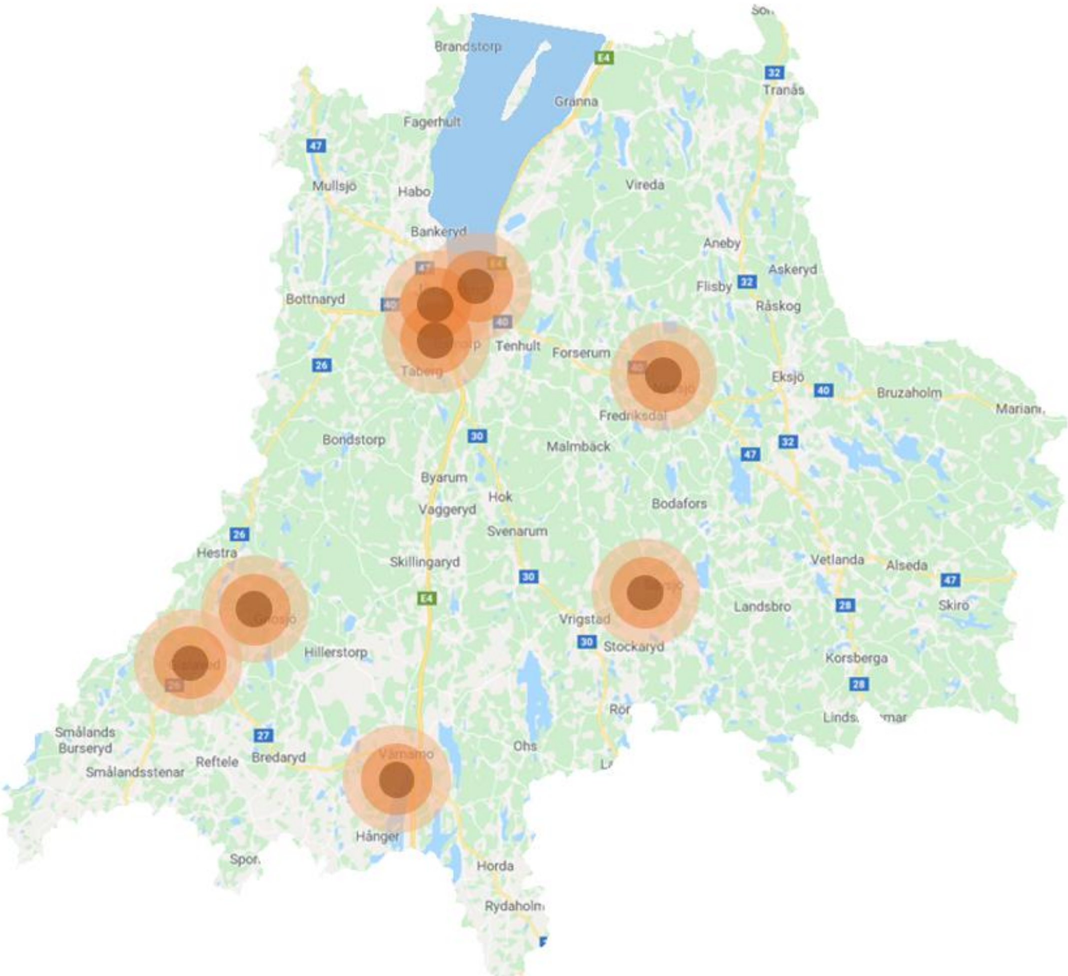

Figure 9. Refueling stations for CBG within Jönköpings County, with zones added for 5, 10 and 15 km from the refueling station [75].

In total, 45 GWh of biogas were used in the region in 2017 – mainly for public transport (Figure 9). At the same time, almost 3000 GWh of gasoline and diesel were used (Table 3), mostly for cars and heavy trucks (Figure 10).

Table 3. The amount of gasoline and diesel that was refueled within the region of Jönköping during 2017 [76].

Fuel	Fuel use (GWh)
Gasoline	1200
Diesel	2500

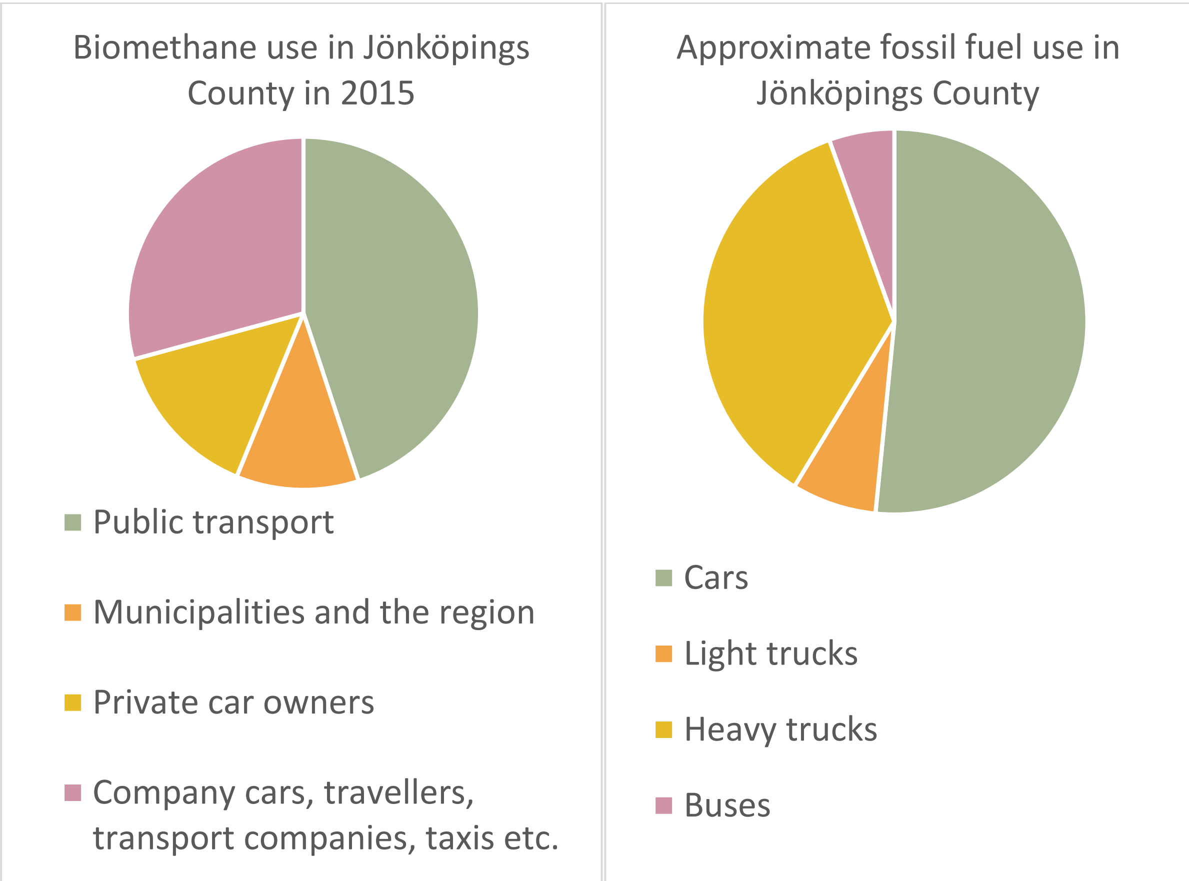

Figure 10. *To the left is the biomethane use in Jönköpings County in 2015, divided into how it was used [9]. In total, 45 GWH of biomethane was used in the region in 2015 [9] To the right is an approximation of the fossil fuel use in the transport sector in Jönköpings County divided into usage area and based on statistics [76], [77].*

6.1 Public transport

The public transport that could be using biogas is in Region Jönköping divided into three parts: city buses within Jönköping, regional buses and service trips. The segment with regional buses also includes city buses in Tranås, Vetlanda, Nässjö and Värnamo.

For city buses in Jönköping, the fuel use in 2016 was in total 39.6 GWh of which biogas was 15.7 GWh, used for 30 gas-driven articulated buses. Technically, the biogas use in this segment could thus increase with over 20 GWh if the city buses that are not using biogas also would be changed to biogas-use [9]. However, according to recent procurements, parts of the city buses in Jönköping will be battery electric vehicles from 2021 [78]. In total, the procurement has stated that all city buses in Jönköping will be using either electricity or biogas between 2021 and 2031, and that the main lines will be electrified [79].

The regional buses were in 2016 not using any biogas but has the potential to do so and parts of the Biogas Agreement was that biogas was to be used for regional buses. In the recent procurements for regional buses, which is an agreement between 2020 and 2030, it was stated that the buses will be driven by both biogas, biodiesel and electricity [80].

Apart from buses, there are also service trips (i.e. taxis) using biogas, which used a total of 4.75 GWh of vehicle gas in 2015 [9].

6.2 Publicly owned vehicles

All the municipalities that hade refueling stations for biogas within their municipalities were partly using biogas in their vehicles in 2016 (Table 4).

Table 4. *The number of gas-vehicles and the use of biogas in publicly-owned vehicles during 2016 [9]*

Municipality/ Region	Cars	Small trucks	Heavy trucks	Vehicle gas use (GWh)	Refueling stations
The region of Jönköping	39	16	-	?	
Jönköping	297	173	9	2.9	3
Värnamo	35	5	-	0.68	1
Nässjö	17	13	2	0.49	1
Gislaved	33	9	-	0.21	1
Vetlanda	1	-	-	?	0
Tranås	-	-	-	-	0
Eksjö	-	-	-	-	0
Vaggeryd	-	-	-	-	0
Habo	-	-	-	-	0
Sävsjö	15	-	-	0.15	1
Gnosjö	17	2	-	0.13	1
Mullsjö	-	-	-	-	0
Aneby	-	-	-	-	0

6.3 Cars

In Jönköpings County, one third of all the cars are registered in the municipality of Jönköping, which also has more than half of all the gas-driven cars in the region as well as 3 refueling stations for CBG. Apart from Jönköping, the other five municipalities that also have gas-refueling stations all have 0.5-0.9 % gas cars – in contrast to the 0.2-0.5 % of the municipalities that do not have any refueling station for gas. According to figure 11, there seems to be a connection between the share of gas vehicles in the fleet and the number of gas refueling stations in the municipality.

Municipality	Total number of cars	Gas-driven cars	Percentage	Gas refueling stations
Jönköping	67608	816	1.2 %	3
Värnamo	19333	88	0.5 %	1
Nässjö	16339	74	0.5 %	1
Gislaved	16675	145	0.9 %	1
Vetlanda	15870	36	0.2 %	0
Tranås	9453	41	0.4 %	0
Eksjö	10005	21	0.2 %	0
Vaggeryd	7809	39	0.5 %	0
Habo	6485	27	0.4 %	0
Sävsjö	6480	60	0.9 %	1
Gnosjö	5541	37	0.7 %	1
Mullsjö	3979	19	0.5 %	0
Aneby	3979	19	0.5 %	0

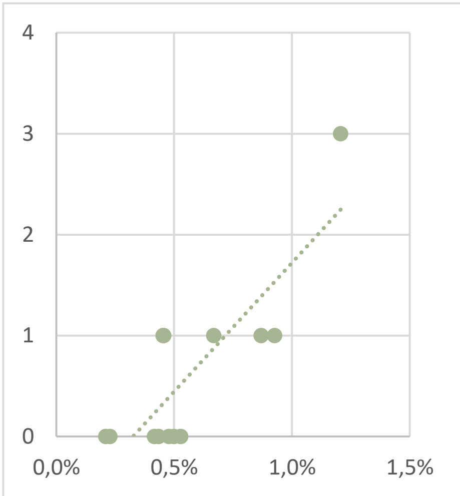

Figure 11. The number of cars, gas-driven cars and gas-refueling stations in the municipalities in Jönköpings County. To the right is a figure showing the potential relationship between the number of gas refueling stations in the municipality and the percentage of gas-driven vehicles in the fleet in the municipality.

6.4 Light trucks

Regarding light trucks, the number of vehicles is ten times smaller than the number of cars [77]. However, compared to the cars, there is an even higher concentration in the municipality of Jönköping – both considering the share of light trucks in the region as well as the share of gas-driven light trucks [77]. The number of light-trucks is especially high in Sävsjö and Nässjö (apart from Jönköping) (Figure

12) – but considering that the total number of vehicles is lower than for cars, each gas-driven vehicle will have a higher impact on the statistics of the shares.

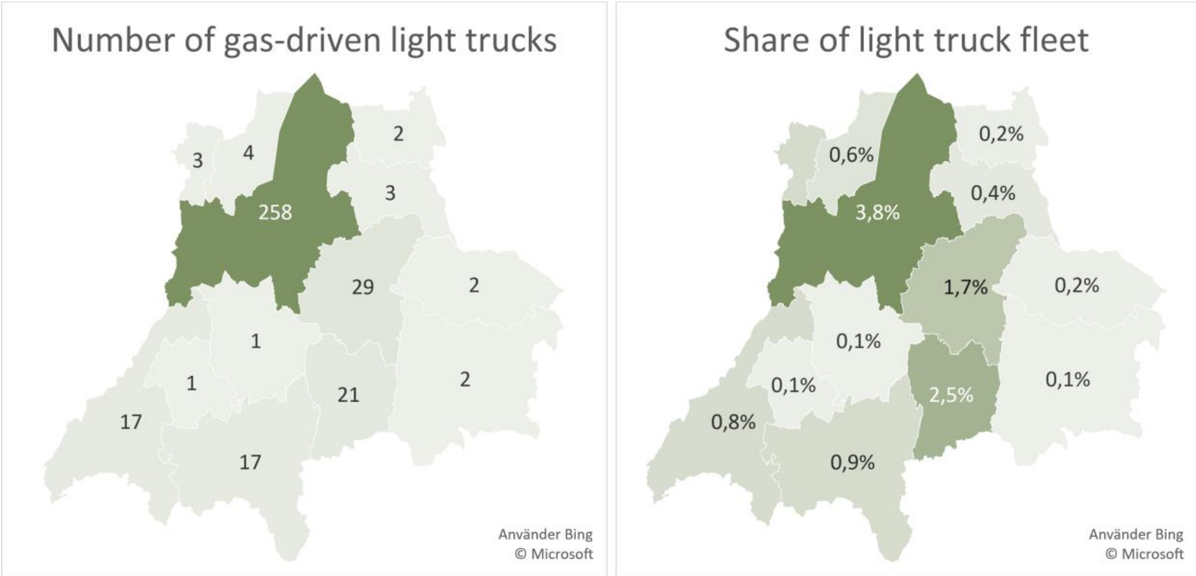

Figure 12. The amount of gas-driven light trucks (left) and the regional share of the light truck fleet (right) [77].

6.5 Heavy trucks

For heavy trucks, there are only 19 gas-driven vehicles in the region (0.5 % of all the heavy trucks) – 13 of which are in Jönköping. Regarding the other 6 trucks, Habo, Vaggeryd and Nässjö has 2 gas-driven heavy trucks each [77]. Even though this transport segment has only 3500 vehicles in total, it is still estimated to be one of the most fossil-fuel using segments and each gas-driven heavy truck will have a much larger impact than a replaced car.

In contrast to cars and light trucks, many heavy trucks are going longer distances to transport things [81]. In Jönköpings County, this transport of goods is especially centered along the E4 (i.e. Jönköping, Vaggeryd and Värnamo) and road 40 to Gothenburg (i.e. Jönköping). South of Jönköping, in Torsvik, there is also one of the largest logistic centers in Sweden where for example IKEA and Elgiganten [82] have large distribution centers.

There is an ongoing expansion of the LNG/LBG refueling network, which Jönköpings County is part of with e.g. the refueling station in Torsvik south of Jönköping. Both Scania and Volvo also have newly-released LNG/LBG trucks that can be used for heavier haulage and longer distances than previously existing biogas-driven heavy trucks, and there are several large truck users that are now trying out LNG/LBG – for example IKEA [83], Elgiganten [82] and Axfood [84].

6.6 Industrial use

Apart from the transport sector, fossil fuels are also used in industries. In Jönköping County, around 300 GWh of liquefied petroleum gas (LPG)/natural gas and 100-200 GWh of oil products were used in industries in 2013 [85]. Parts of this energy use is classified information which makes it difficult to get accurate approximations of what businesses there are that use the fuels. Due to this difficulty, only one industry, Waggeryd Cell, is further showed as an example since information about their fossil fuel was found while studying the industry for its potential substrates.

Apart from having potential substrates, the pulp industry Waggeryd Cell could also use biogas themselves. Their current production system sill uses 36 GWh of fossil fuels [51], but their pulp production has a potential to produce around 22 GWh of biogas per year. Thus, almost two thirds of the fossil fuels they use can be replaced with biogas that could be produced from waste streams in their process.

7. Actors

Key actors for biogas within Region Jönköping are the municipalities, especially considering the Biogas Agreement where the municipalities agree to work towards increased biogas use and production. The municipalities can be important actors in many different ways – they are responsible for organic waste and wastewater sludge that could be turned into biogas, several of them own wastewater treatment plants where biogas is produced, they can use public procurement to buy biogas-using vehicles and so forth.

Apart from the municipalities, there are also a few other actors that produce biogas in the region (Figure 13). The old biogas plant in Jönköping has recently been sold to Hitachi Zosen Inova, who are also building a new plant in Jönköping for dry digestion that is going to take over from the old plant which will be shut down. The other co-digestion plant (which also upgrades the biogas to CBG), Sävsjö Biogas, has two owners – Biond, who owns 90 % of the plant and who also runs the biogas plant in Helsingborg, as well as Vrigstad Fjärrvärme, who owns 10 % and consists of a number of farmers in Sävsjö. Apart from those two, there is also a smaller farm-based plant owned by Långhult Biogas AB, which primarily uses manure as substrate from the owner's farm.

For the gas upgraded to CBG, i.e. gas from the co-digestion plants in Jönköping and Sävsjö as well as the wastewater treatment plant in Jönköping, the gas is distributed and sold in refueling stations by Fordonsgas. Apart from Fordonsgas, E.ON. also have refueling stations for CBG in the region – in the gas-grid-connected Gnosjö and Gislaved, as well as one refueling station in the nearby town Värnamo. Since earlier this year, there is also LNG/LBG refueling station in Torsvik, south of Jönköping, owned by Gasum.

Among the users, important private actors are for example the different taxi businesses that operate several gas-driven cars. There is also Elgiganten, whose collaboration with Gasum and Volvo is what led to the LNG/LBG refueling station in Torsvik. For the farm-based biogas plant (Långhult Biogas), important actors are Bixia who buys the electricity that is produced from burning the biogas in a CHP-plant, and Söderlinds Ekologiska Grönsaker who buys the heat.

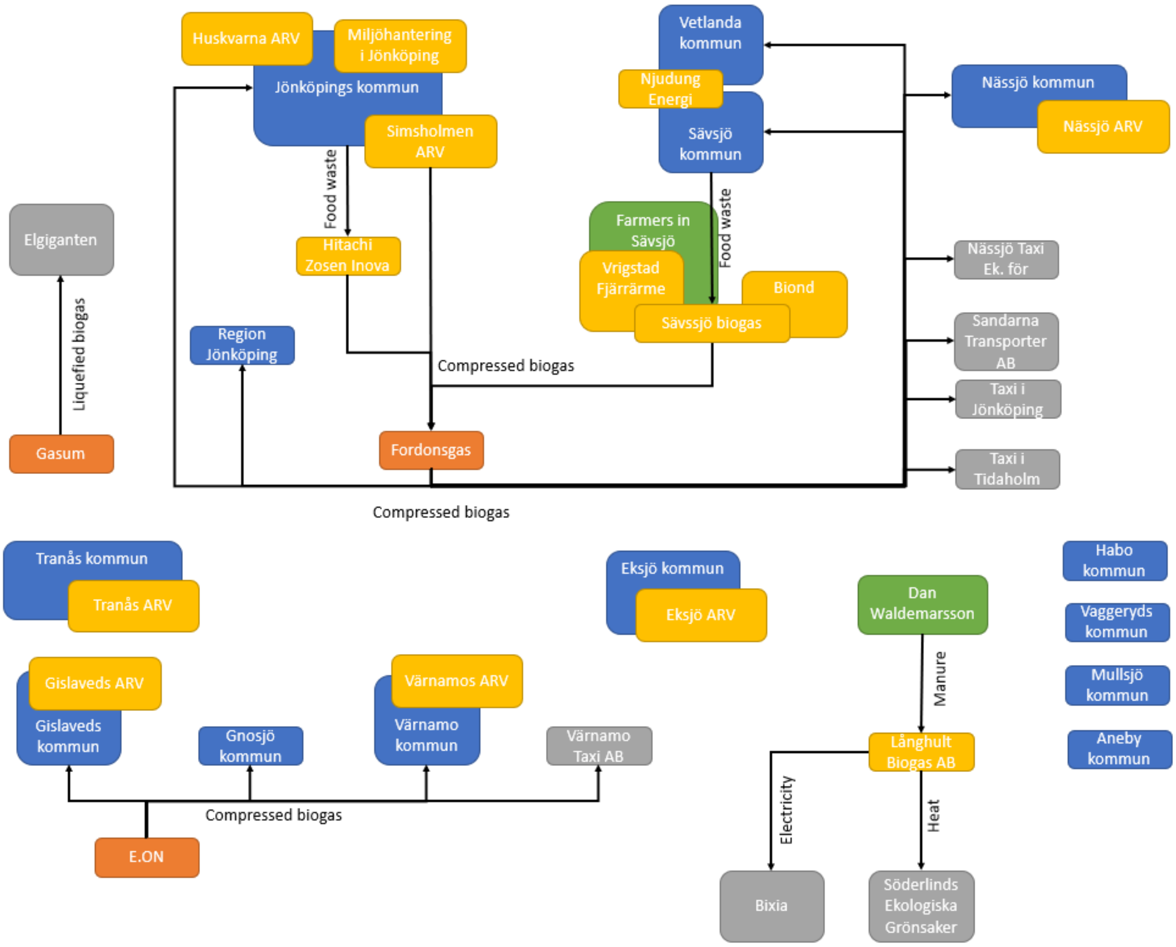

Figure 13. *Some important actors related to biogas in Region Jönköping, with arrows to represent how they are connected. The colors represent different things. Blue=public organizations, green=substrates, yellow=biogas producers, orange=biogas distributors, grey=biogas users.*

To achieve an increased biogas production and use, other actors can also be important. To acquire substrate, several different farmers or companies dealing with organic waste streams can be important. An important aspect regarding this is trying to find farmers, companies or other actors with potential substrates that are in close proximity with each other. Another actor that might become of more importance in the future is Gasum – they are rapidly building a large network of LBG refueling stations, and have expressed in personal communications that they are now looking at how the biogas production in Sweden can be greatly expanded.

An extremely important part of the biogas-related actors is also the users, since there need to be a market for the biogas in order to increase production. Future important actors in this regard can be several different alternatives. Cars emits large amount of greenhouse gases, and private car owners can thus be important users if there is enough of them. Several other actors can become important in order to make private car owners choose biogas cars – such as auto repair companies that have knowledge of biogas, companies selling biogas cars and companies that convert gasoline cars to run on biogas instead. Those actors could also be of importance in order to increase the interest of light trucks in the region. Regarding heavy trucks, Jönköping County is an important logistic center – especially the Torsvik area. Since Jönköping and Torsvik is also where the LBG refueling stations are, future key actors that can be targeted for biogas use are companies having distribution centers or other facilities close to Torsvik or Jönköping. However, since all the vehicle fuel that is produced from regional-biogas is in the form of CBG rather than LBG, other potential users should be prioritized in order to improve the market for the biogas produced in the region.

8. Drivers and barriers

An overview of drivers and barriers for biogas solutions in Jönköping County can be seen in Table 5. A major driver for carrying the development of biogas solutions in Jönköping County is the Biogas agreement, which has been signed by the municipalities as well as the region. To have these types of connecting document gives a foundation to work on and partners have something to answer to if the development stagnates. The governmental demand that municipalities should provide household with a system for sorting food waste is also an important driver for collection of substrate for future biogas solutions [86].

Drivers	Barriers
Biogas agreement	Coordination of actors
International, national and regional goals	Policies
Interest in organic farming	Contract requirements
Policies	Investment costs
Contract requirements	Transportation of the gas and substrate
Governmental demand on sorting food waste	Lack of infrastructure
	Large scale of the fossil fuel use

Table 5. *Overview of drivers and barriers for biogas solutions*

Also, international, national and regional climate goals are of course important drivers to invest in biogas solutions. When looking at the digestate side, organic farming can be seen as a driver for creating a good market for it. Digestate is one of few options for organic farming, and the increasing demand for organic food [87] could thus drive the profitability for digestate. There are some factors that fit both as barriers and drivers. For example, depending on how they are formulated policies can act as both a driver and a barrier for biogas use [3]. The same things goes for contract requirements – they can act as both a driver or a barrier depending on what the requirements state [18].

When looking at the barriers, coordination of actors is something that can problematic and can be a barrier if not handled well. Investment costs and profitability in biogas solutions could also be a barrier especially when looking at small-scale solutions. Infrastructure and transportation are also barriers that need to be handled. This can be connected to the transportation of the gas as well as the substrate. In the substrate area it is especially important as one of the main substrates identified is manure. A final barrier to discuss is the structures that we have in society connected to the use of fossil fuels. The amount of gas cars is still around one percent [77] indicating that there is still a long way to go in the shift from fossil fuels to gas vehicles.

9. Plan for a new biogas production plant

One of the tasks of the biogas solution course was to suggest the implementation of a new biogas plant in that region based on the case study, which will be described below.

9.1 A plant in the Värnamo/Gislaved area

The suggested location for the implementation of a new biogas plant is between the municipalities of Värnamo and Gislaved. The choice of this location is due to the large amount of feedstock – there is a large number of livestock in the region and a potential to use manure as a substrate for biogas production. Also, the cities close by are working on a system for food waste collection.

If all these substrates were used for biogas production, the realistic case scenario would result in a total yearly production of 23.7 GWh.

According to the substrate inventory of the region previously described and also presented in Table 6, the Värnamo and Gislaved location presents a four different types of substrate that are of main interest: the food waste from Alvesta, Ljungby, Svenljunga and Tranemo, liquid manure, swine manure and chicken manure. If all these substrates were used for biogas production, it would result in a total yearly production of 23.7 GWh.

Table 6. *Overview of substrate sources, approximate yearly amounts and potential yearly production from the suggested plant, based on potential calculations presented in previous chapters. The numbers are based on the realistic scenario.*

Substrate fraction	Amount*	Unit	Yearly potential biogas production (GWh)*
Food waste (SÅM-region: Alvesta, Ljungby, Svenljunga & Tranemo	9 440	tonnes/year	9.0
Liquid manure	50 000	m3 WW/year	7.5
Chicken manure	2 000	Tonnes VS/year	3.3
Swine manure	9 00	Tonnes VS/year	3.9
		Total production	**23.7**

*Based on potential calculations

For these types of substrates, the most appropriate process is wet co-digestion since it works with more than one substrate and can produce more biogas than expected from the individual substrates since the different materials complement each other deficiencies [16]. Co-digestion should occur in the range of 2-10% of Total Solids (TS). One of the most widely used design of reactor used to this kind of substrate is the Continuous Stirred-Tank Reactor – CSTR. This type of reactor presents more flexibility, can work with a wide range of substrate from 2 to 10 % up to 15% of TS [88] and Commonly convert between 50-70% of the organic matter into biogas [16].

Food waste have around 35% of TS and cow manure a wide range between 15-75% of TS [28]. So, it is necessary to dilute the substrate to achieve the optimal solids concentration for CSTR reactor that is between 4 to 8% [89]. A good possibility found in the region is to use dairy wastewater of Arla's Industry (cleaning water) for dilution of the substrate, that can contribute to reducing water use for substrate dilution as well as contributing with methane production. Also, dairy wastewater has a high pH (between 6.6 and 12) [90], what can contribute to the balance of the substrate pH since food waste have low pH [91].

In addition, mesophilic operation temperature condition of 38 ˚C is suggested for the AD. Because manure has high ammonia concentration [88] and can cause system disturbance and instability under thermophilic conditions. Furthermore, Swedish legislation requires a hygienization process to eliminate potential pathogens in the digestate for further application as a fertilizer (SPCR 120) and protect human and animal health also, the quality of the crops [92]. This hygienization process should be at least for one-hour at 70 ˚C. This means that this process may be prior to AD and the high temperature may collaborate to the maintenance of the CSTR reactor temperature.

As a possible supply of heating, there is an energy cogeneration industrial plant in Värnamo that produces heating using 98.54% of renewable fuels such as forest wastes [93]. That could be an example of industrial symbiosis.

9.2 A plant in connection to Waggeryd Cell

Another possibility of biogas production studied in the Jönköping region is to use the paper and pulp wastewater of Waggeryd Cell AB in the Vaggeryd municipality (previously described in item 4.6.1). The calculated values for a potential plant are 21.6 – 22.8 GWh per year based on Waggeryd current pulp production. Withal, these values could help justify the possible implementation of a biogas upgrade unit.

However, for this potential substrate (pulp and paper wastewater) a CSTR is not best choice for a process design. Other types of reactors are more suitable for wastewater treatment, such as Upflow Anaerobic Sludge Blanket (UASB) and Internal Circulation (IC), that works with high rate and low suspended solids content [5].

UASB is the most common type of reactors used for wastewater treatment. This reactor has topworks (settler) that is responsible to the high efficiency due to the biomass retention inside the reactor and the no need energy consuming for mechanical stirring [16].

The IC reactor separates the biogas in two stages and do internal circulation of the effluent. Due to this, this reactor may enable the treatment of wastewater in lower hydraulic retention time and higher organic loading rate when compare to UASB. Which means that this reactor has higher efficiency in biogas conversion, especially for pulp and paper wastewater treatment [94].

10. Limitations and possible future studies

For all substrate potential calculations, there are uncertainties regarding where the substrates are and how much there is. This could be further studied by using for example GIS to produce a map where all substrates from specific actors are pinpointed more exactly, in order to have better approximations of where exactly the substrate is located. For some substrates, the total potential was not included at all and are thus also obvious possibilities for further studies. The same goes for digestate – a more detailed mapping could be made with a GIS map of different nutrients, where there is livestock and where there is arable land in order to see how the maps overlay – e.g. to find spots where there are an abundance of nutrients, or where there are arable land without much livestock and with a lack of nutrients.

Regarding current and potential users, much more could be developed and studied. In several cases, there were difficulties with finding information that gave a good overview of what potential actors there are in the region. Such a mapping of potential users (i.e. industries using fossil fuels or companies operating light or heavy trucks) could, however, be achieved with more time. Due to similar issues, actors with potential substrates (e.g. different kind of food industries) could also be mapped better with more time for it.

Since this was a study focused on Jönköping County, the system boundaries were set to focus on actors inside the county. However, there are likely possibilities for actors outside but close to the county to interact with the biogas system in Jönköping – for example actors with potential substrates, or potential users. A broader study looking into the synergies with other areas could thus also be done.

Another thing that could be further developed is to have more contact with the key actors, such as the municipalities. There could, for example, be workshops held where the key actors met and discussed how biogas can be better marketed in the region, what developments need to happen for production and use to increase and so on.

What is considered as most important to study by us is, however, to further focus on possible areas where there is potential for new biogas production plant – i.e. studies focused on a particular area and the nearby substrates, users, infrastructures and so forth in order to better understand what potential there is for building a production plant there. This could also be achieved by workshops, where actors situated in a small area meet and discuss how they can be a part of a biogas system, and how it can be achieved.

11. Conclusions

Most of the substrate available in the Jönköping region for biogas production is manure, especially from cows. However, there is no huge concentration of farms and arable lands.

The single largest source of GHG emissions in the region is the transport sector. But in our study, we found that there are more fossil fuels in the transport sector being used today than can be substituted with biogas, even with a utopian increase of biogas production.

It is suggested to build a biogas plant between the cities of Värnamo and Gislaved because these cities have a large supply of substrate such as manure and food waste. The CSTR reactor with mesophilic wet co-digestion process was chose in this case because it presents the best conditions for the anaerobic digestion of these kind of substrate. Also, it was identified the possibility to build a biogas plant for pulp and paper wastewater in the region of Vaggeryd.

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Appendix I – Manure

The approximations of manure amounts and locations are based on the farms that are either "anmälningspliktiga" or "tillståndspliktiga", i.e. that have either between 100 < 400 animal units or above 400 animal units. The information is given either from the respective municipalities or from the region, depending on who is responsible. The number of animals has been recounted into animal units according to Jordbruksverket. The table shows number of farms with a certain amount of animal units of cows, chickens and pigs

<table>
<tr><th></th><th>Cows</th><th>Chickens</th><th>Pigs</th></tr>
<tr><td colspan="4">Jönköping</td></tr>
<tr><td>100 < 200</td><td>x21</td><td>x1</td><td>-</td></tr>
<tr><td>200 < 300</td><td>x3</td><td>-</td><td>-</td></tr>
<tr><td>300 < 400</td><td>x2</td><td>-</td><td>-</td></tr>
<tr><td>> 400</td><td>x1</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Värnamo</td></tr>
<tr><td>100 < 200</td><td>x8</td><td>x3</td><td>-</td></tr>
<tr><td>200 < 300</td><td>x6</td><td>-</td><td>-</td></tr>
<tr><td>300 < 400</td><td>-</td><td>x1</td><td>x1</td></tr>
<tr><td>> 400</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Nässjö</td></tr>
<tr><td>100 < 200</td><td>x11</td><td>-</td><td>-</td></tr>
<tr><td>200 < 300</td><td>x1</td><td>-</td><td>-</td></tr>
<tr><td>300 < 400</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>> 400</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Gislaved</td></tr>
<tr><td>100 < 200</td><td rowspan="3">x16</td><td>-</td><td>-</td></tr>
<tr><td>200 < 300</td><td>-</td><td>-</td></tr>
<tr><td>300 < 400</td><td>-</td><td>-</td></tr>
<tr><td>> 400</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Vetlanda</td></tr>
<tr><td>100 < 200</td><td>x7</td><td>-</td><td>-</td></tr>
<tr><td>200 < 300</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>300 < 400</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>> 400</td><td>x1</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Tranås</td></tr>
<tr><td>100 < 200</td><td>x12</td><td>x1</td><td>-</td></tr>
<tr><td>200 < 300</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>300 < 400</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>> 400</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Eksjö</td></tr>
<tr><td>100 < 200</td><td>x12</td><td>-</td><td>-</td></tr>
<tr><td>200 < 300</td><td>x1</td><td>-</td><td>-</td></tr>
<tr><td>300 < 400</td><td>x1</td><td>-</td><td>-</td></tr>
<tr><td>> 400</td><td>x1</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Vaggeryd</td></tr>
<tr><td>100 < 200</td><td>x5</td><td>-</td><td>-</td></tr>
</table>

200 < 300	-	-	-
300 < 400	-	-	-
> 400	-	-	-
Habo			
100 < 200	x4	-	-
200 < 300	x2	-	-
300 < 400	-	-	-
> 400	-	-	-
Sävsjö			
100 < 200	x24	-	-
200 < 300		-	-
300 < 400		-	-
> 400	x2	-	-
Gnosjö			
100 < 200	-	-	-
200 < 300	-	-	-
300 < 400	-	-	-
> 400	-	-	-
Mullsjö			
100 < 200	x1	-	-
200 < 300	-	-	-
300 < 400	-	-	-
> 400	-	-	-
Aneby			
100 < 200	x10	-	-
200 < 300	-	-	-
300 < 400	-	-	-
> 400	-	-	-

Appendix 2 – Total estimation of production

Potential substrates	Realistic (GWh/year)	Utopian (GWh/year)	Comments
Cattle manure	133.5 – 229.8	354.9 – 612.7	Utopian case, count is if all the manure is collected and digested. Realistic 50% collection and 75 of methane potential acquired in continuous process
Sheep manure	0,7	1.82	-''-
Swine manure	1.2–5.2	3.2-14.0	-''-
Chicken manure	0,7	1.9	-''-
Liquid manure (Reftele report)	-	7.0	-‘’-
Municipal household waste (food waste)	16.8-26.5	32.9-49.4	Collection 47 kg/person and year, 60 kg/person and year and 97 kg/person and year
Wastewater streams form Waggeryd Cell	21.6-22.8		Estimated from that 0,13 MWh can be produced per ton pulp produced
Waste streams from Munksjö Paper AB	NA	NA	Need more information of exact stream types and volumes
Agricultural waste	NA	NA	
Waste from candy production in Gränna	NA	NA	1100 tonnes of candy produced, have not identified exact waste streams, potential product for co-digestion. Have been shown to improve processes with cow manure
Cleaning waters from Arla	NA	NA	Possible to use for dilution instead of water in processes
Potential from Municipal wastewater	25	25	
Total	187.7-278.8	456.8-743.1	