Biogas production based on park waste

- Does Helsingborg have the potential?

NIKOLINE GUSTAFSSON 2019

MVEM12 MASTER'S THEISIS 30 CREDITS

ENVIRONMENTAL SCIENCE | LUND UNIVERSITY

Nikoline Gustafsson
MVEM12 Master’s theisis 30 credits, Lund University
Internal supervisor: Torleif Bramryd, Department of service management and service science, Lund University –Campus Helsingborg.
External supervisor: Widar Narvelo, Helsingborg city developing department.

CEC – Centre for Environmental and Climate Research
Lund University
Lund 2019

Cover sheet image: Meadow in Jordbodalen Helsingborg. Photography by Widar Narvelo.

Abstract

Biogas is a renewable fuel produced from various kinds of organic biomass primarily considered as waste from today's society. The biogas today are used as fuel in heat and electricity or upgraded to vehicle gas. There are ambitious national and local targets for biogas in Sweden, where within a few years they want to see a comprehensive increase in production and use of biogas. Likewise, it’s becoming increasingly popular that cities strive to become more circular with their resources by consider waste as a resource. This is something Helsingborg city development department is working on right now, by giving the plant-based waste from park areas in Helsingborg a new purpose as a substrate in local biogas production.

The study investigated the potential of using park waste in biogas production, but also briefly examine whether it’s possible to strengthen the circular aspect by producing biochar from the digestion residue. The result show that there is a potential in producing biogas from park waste, but with the digestion technique available in Helsingborg today, only the soft and moist fractions can be digested. The most optimal would be to build a dry-digestion plant in Helsingborg, since this kind of plant can digest all fractions from the park waste. Furthermore, the result showed that the digestion residue are best suited as a biofertilizer and it can be considered unnecessary to produce biochar from it. In conclusion, the result is only considered as an indication since no practical tests have been performed.

***Keywords*:** Biogas, circular society, resources, biogas substrate, park waste, biofertilizer, biochar.

Table of Contents

1. Introduction

1.1. Background

At present, climate change is a topic that permeates our society in one way or another. There are a number of different actions that cities can take to reduce their climate impact, one way is to move away from a fossil society by using biofuels to a greater extent. Furthermore, a more circular society can contribute to lower climate impact, a step in that direction would be to start seeing waste as a resource. Helsingborg city is one of the largest towns in Skåne. Likewise Skåne's approach plan for Biogas, Helsingborg has its own climate and energy plan “climate and energy plan 2018-2024 Helsingborg” where they mention biogas as one way towards a sustainable society.

Skåne is a county in southern Sweden and according to the report "Skåne's approach plan for Biogas", the strategic goal is that Skåne will become Europe's leading biogas region before 2030. A way to achieve this goal is to use knowledge and local resources in a more efficient manner (Region Skåne, 2015). Skåne wants to strive for increased production, distribution and consumption, and work for long-term conditions for biogas and biofertilizer. The potential for using more sustainable energy systems where, among other things, biogas is included is considered to be large. In the transport sector, Skåne has also set a goal of working to convert to fossil-free fuels (Skåne County Administrative Board, 2018).

A regional product of biogas and biofuels is considered important for the creation of a sustainable society. Above all, it contributes to a cycle of energy between city and country, but also because it creates jobs and safer fuel supply (Skåne County Administrative Board, 2018). For example, one can see a trend in which industries in Skåne have in recent years used a greater amount of biogas instead of the natural gas they would otherwise have used as an energy source. The number of filling stations for biogas will increase in Skåne County (Skåne County Administrative Board, 2018), which will increase accessibility and may also contribute to increased demand for biofuels. At present, Skåne's biogas potential amount to 3 TWH, but recently the market has been unstable, which has led to lower investments in biogas production. The regional production of biogas and biofuels in Skåne is not sufficient, which means that the market is still dependent on external imports (Skåne County Administrative Board, 2018). Actions to that stabilize and develop the biogas market are needed. That means continuous work to develop the market and to work with the technical development of production and use of biogas and biofertilizer in Skåne are needed (Skåne County Administrative Board, 2018).

The majority of the biogas produced in Helsingborg is based on the digestion of process waste from the food industry and source-sorted food waste, the production takes place at NSR (Northwest Scania Recycling Company). Biogas is produced from the digestion of sewage sludge at the sewage treatment plant in Helsingborg, owned by NSWA (Northwest Skåne's Water and Sewerage). Also NSR produces biogas from biogas plants and from landfills. This gas is used for heat and electricity production in plants owned by Öresundskraft. (Helsingborg city, 2018). The primary use of the biogas in Helsingborg is as fuel for bus traffic. However, there are incentives for bus traffic to gradually shift to pure electric power according to Region Skåne, since electric motors contribute to lower noise levels (Helsingborg city, 2018). Helsingborg works actively to make the biogas as vehicle fuel more attractive by, for example, developing the infrastructure regarding the filling stations for biogas within the city. The goal is that the deposition of locally produced biogas will have increased by 15% by 2024 compared to the levels in 2016, which were 7140 tones (Helsingborg city, 2018).

Helsingborg climate and energy plan 2018-2024 (figure 1) aims to work for a better climate and better management of local resources, for example increasing the proportion of sustainable transport. The plan also predicts that biogas production will increase between this time span, primarily because the volumes of collected substrate will increase. But a prerequisite for increased production of biogas is that there is a local provision for the biogas produced (Helsingborg city, 2018). Another aspect that is addressed in Helsingborg climate and energy plan 2018-2024 (figure 1) is carbon storage, where one wants to increase the storage of carbon dioxide in soil and vegetation. One method for this is to produce biochar from organic materials, such as wood material, which is then used as soil improvement material. Helsingborg has already tested biochar as soil improvement in urban environments and there potential to expand the use (Helsingborg city, 2018).

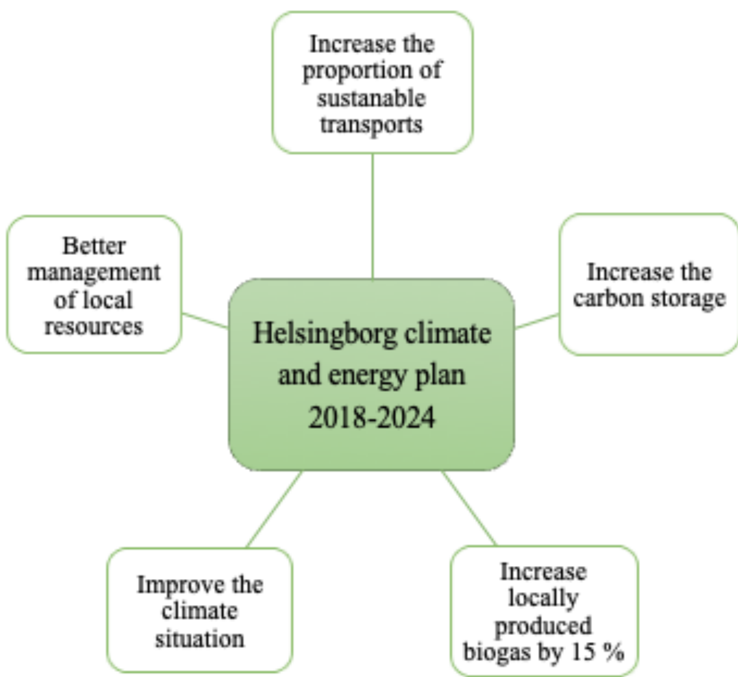

Figure. 1; Goals and aspects from Helsingborg climate and energy plan 2018-2024 related to this study.

1.2 Case study

Every year the public parks and green spaces including meadows, shrubs, trees and flower beds in Helsingborg generate big volumes of plant waste from an total area of 373.8 hectare. At present, all this plant waste is put on a compost or remain at the place of the occurrence, which can be seen as an inefficient way of using the natural resources within the city. This case study will therefore only focus on the potential of producing biogas from the plant waste generated by Helsingborg city.

The reason a case study chosen to be implemented is because the purpose of the study is to reinforce a theory (Denscombe, 2014), which in this case is that plant waste is considered to be an alternative substrate for biogas production. The study will investigate whether it is profitable in the future to use plant waste as a biogas substrate, compared with, for example, a cross-sectional study where a certain condition is examined at a specific time (Ibid). Furthermore, a case study allows to look more closely at certain aspects in a situation and go into more details and examine whether the theory is feasible in reality (Ibid).

The aim of this study is to, on behalf of Helsingborg city development department, theoretically investigate the potential and profitability when it comes to biogas production of residual waste from the park management. Furthermore, this study will link the local environmental and climate goals in Helsingborg city to the positive aspects of biogas production, investigate which plant waste could be used for biogas production and lastly will this study investigate how digestate residues from biogas production can be useful in optimizing a circular economy. This study will hopefully later serve as an incentive to use waste from city’s park and green areas in future projects regarding biogas productions.

1.3 Demarcation

This report focuses on the capacity of producing biogas from residual waste from the park management in Helsingborg city. The potential in this study can be identified by merging aspects regarding the willingness/interest, financial and technical together. Due to the broad spectrum of different kinds of plants that turn into waste in Helsingborg, this study will not look in to any specific plant species, instead divide it into two different fractions that include one green soft and juicy fraction (grass, meadows, flowers, leaves) and one woody fraction (tree twigs, branches, shrubs).

1.4 Aims and Research questions

The purpose of this study is to investigate whether there is a benefit and possibility to use the park waste generated by Helsingborg city to locally produce biogas from it. The goal is to create an overall picture if it is possible or not to produce biogas from park waste in Helsingborg, describe what incentives there are to actually start up such biogas production in the future. In addition, the study will explain how the digestion residue may practically be used after digestion of park waste. The study will also create a technical overview of which aspects are important to consider when assessing the process of making biogas of different materials.

Through three main questions the purpose of this study will be fulfilled, and to clarify what each question aims to investigate, 8 sub-questions have been developed for each main question:

1. Can residual products from the green park areas in Helsingborg be used as a substrate in biogas production?
   - Is there a will/interest in using residual products from the green areas?
   - Is it technically feasible?
   - Is it economically feasible?
   - Are there any political incentives?

2. Which plant materials from the park waste are suitable for use in the biogas production?
   - Which materials are suitable for use in the production of biogas?
   - What kind of production technique are the most efficient?
   - Can the residue from the biogas production be used for the production of biochar?

3. What can the the digestion residue from the biogas production of park waste be used as?
   - Can the digest residue from the biogas production be used for the production of biochar?
   - Does park waste fit better as substrate within biochar production or biogas production?

2. Method

2.1 Collecting data

These studies were based on two different data collection methods. First, the literature was collected from relevant scientific literature, reports from similar projects regarding biogas and material from Helsingborgs city archive. The literatures and reports were collected from the scientific search websites *Web of science, LUBsearch and Google Scholar.* The keywords used in the websites were *biogas technique*, *biogas* AND *garden waste*, *biogas substrate*, *biogas yield*, *biogas production*, *biogas* AND substrate AND properties, *digestion residue*, *compost* AND *properties*, *biogas* AND *meadow*, *biogas* AND *grass, biogas* AND *wood*, *biochar*, *biofertilizer*. Second, nine qualitative semi-structured interviews were conducted with relevant actors, scientists and project managers active within different biogas projects.

To answer the first question in this study where the potential for biogas production of plant waste is to be investigated, the following aspects were studied:

- Whether it is economically advantageous or not.
- If there is a will or interest from the stakeholders.
- If it's technically feasible.

The result of this question will be based on relevant literature and supplemented with answers from interviews.

The result regarding question number two in this study, concerning which plant material from the park waste that suite the production of biogas the most. Based on the aspects regarding which material has the most physically favorable properties and also which plant waste generates the largest amount of waste in Helsingborg city. The results were based on relevant scientific literature and reports / inventories from Helsingborg city, contact with entrepreneurs and scientific studies.

The result of the last and third question concerning circular economics regarding the digestion residue and the use of the residue from biogas production will be based on interview responses and supplemented with scientific literature.

2.2 Literature review

The literature study was conducted to create an increased knowledge of biogas in general and plant material for the production of biogas in particular. The literature studied includes articles and scientific reports on biogas, statistics and reports from authorities especially Helsingborg city, information from stakeholder organizations and other studies concerning biogas.

The scientific publications used in this study were conducted by using the scientific websites; Web of science, Google Scholar and LUBsearch, where adequate keywords (2.1) related to the purpose of this study was used when searching. In order to obtain information regarding the green/park areas and the amount of plant waste generated in Helsingborg, contact has been made with Helsingborg city administration, they were able to assist with relevant documentation to this stud. Furthermore, relevant studies could also be identified using the snowball method.

The literature study also had the purpose to form the basis for the upcoming interview study. By studying literature from stakeholder organizations within biogas, some interesting biogas plants for the interview study could be identified. There was a good spectrum of elaborated data regarding biogas production and all aspects around the process, however there were only a few studies that particularly investigate biogas produced from meadow species and grass. The literature study included both Swedish and international literature, but since the study were focusing on Helsingborg city, which is located in Sweden, the majority of literature included in this study are based on Swedish conditions.

2.3 Interviews

During a consultation meeting hosted by Biogas Syd, and recommendations from my supervisors from the university and from Helsingborg city, a wide range of potential local and national stakeholders were identified for the interviews.

To get a broad spectrum of answers, seven qualitative semi-structured interviews were conducted with different actors within the biogas area (table 1) considered as stakeholders to this study. There were seven basic questions (appendix 1) which everyone replied to. Furthermore, there were three question areas:

- Production (appendix 2),
- Goals & regulations(appendix 3),
- Biochar & biofertilizer (appendix 4)

And the questions within each question area were specified and directed towards each specific respondent depending on each person's specific area of knowledge. There were seven questions in each question area, some respondent was qualified to answer more than one question area (table 1), which meant that the total number of respondents in this study could be limited to a fewer quantity of people. Four respondents responded within the question area “goals & regulations”, three within “production”, four within “biochar & biofertilizer”.

Table 1; Compilation of information regarding respondents who participated in the interviews, divided into five groups depending on which question area they answered within.

Respondent group	**Number of respondents, title and the company that the respondent represents**	**Question area**
1	1. Environment & Sustainability Manager - NSR. 2. Business development manager - OX2. 3. Project Manager - Stockholm Water and Waste biochar project. 4. Professor of Environmental Strategy - Lund University. 5. Operations manager - Biogas Syd. 6. Project manager - The Energy Agency. 7. Administrative Officer Biogas - Region Skåne.	Basic
2	1. Professor of Environmental Strategy - Lund University. 2. Operations manager - Biogas Syd. 3. Project manager - The Energy Agency. 4. Administrative Officer Biogas - Region Skåne.	Goals & regulation s
3	1. Environment & Sustainability Manager - NSR. 2. Business development manager - OX2. 3. Professor of Environmental Strategy - Lund University.	Productio n
4	1. Environment & Sustainability Manager - NSR. 2. Business development manager - OX2. 3. Project Manager - Stockholm Water and Waste biochar project. 4. Professor of Environmental Strategy - Lund University.	Biochar & biofertiliz er
5	1. CEO - Ekdalens haulage. 2. Researcher - Service management Lund University.	Traffic/lo gistics

During the interviews, it became clear that the transport and logistics aspect was a very important part of the respondents thinking path. Therefore, after the first seven predetermined interviews were completed, two more interviews were conducted, which focused on the transport and logistics aspect (appendix 5). The two respondents within the traffic/logistic question area did not answer the basic questions. Further information regarding the actual logistics for the collection of park waste was obtained through contact with the development engineer Elisabeth Lindkvist at Helsingborg city administration, as well as the two procured contractors PEAB facilities AB and Green landscaping AB, which manages the parks in Helsingborg

Semi-structured interviews were choosen since they open for free responses from the respondents and potentially start interesting conversations (Johannesson & Perjons, 2012). Furthermore, did it also give the interviewer the opportunity to ask follow up questions directly to the respondent. Why questionnaires weren't used is because the aim is to strengthen the result in this study with concrete quotes from different stakeholders.

The actors that were considered to be able to contribute with knowledge of this study are mainly researchers in biogas and municipalities, county councils and authorities are also interesting as they have a good insight into the local and national goals regarding biogas in primarily Skåne, but also nationally and internationally. Both small-scale and large-scale active producers of biogas are interesting interview candidates because they have practical experience and knowledge. And also producers of biochar or biofertilizer could be interesting. Lastly, biogas purchasers are also considered relevant interviewees because they are the ones who will ultimately use the biogas.

2.3.1 Design and time frame

The interview questions were developed based on each participants specific knowledge area, the questions were then discussed with my supervisor at the university, to test the content, technology and equipment, to ensure good quality of the interviews. Based on these discussions, 35 questions were divided into the five categories previously mentioned: basic questions, goal/regulations, production, biochar, and traffic/logistics (appendix 1-5). A pilot test were made on my supervisor at the university, the feedback from the test interviews were then constituted as basis for modification of the final interview questions.

All the total nine interviews were performed over one month's period and the collected data of the answers were gathered in a survey sheet after the transcription. The actors were interviewed over telephone or by physical meetings depending on the geographic distance and each participant's specific wishes. All the questions were sent out via email to all the respondents before the interviews, together with information about how the materials later were used in the study, about being anonymous and how the upcoming interview were structured. The interviews were recorded and later transcript. The interviews were not strictly transcripted word for word. Instead, the responses were compiled into an overall response based on all responses.

2.3.2 Ethics

When gathering data through interviews it is important that the respondents are informed about the aim of the study and what it involves. The respondent was given the option to participate anomalously. If the respondent wants to be fully anonymous, even when it comes to the organizations name, it is the duty of the data collector to not present values that in any way could expose the respondent. In this study, all potential respondents were contacted in advance via email. In the email, information regarding anonymity followed and how the material later will be used in the study. When all the data was collected and compiled, all the respondent were given the option to receive a copy of all the questions and answers, so they have the ability to see what information that supposed to be used in the study.

3. Technical background

3.1 Biogas

By breaking down organic compostable material using microorganisms in an anaerobic environment, biogas can be formed. Biogas can also be formed naturally in environments where the oxygen supply is limited and has sufficient amounts of organic materials, examples of such environments are marshes and landfills, but also in the stomach of cows and other ruminants. This biological process is attempted to mimic in biogas plants, where digestion of various substrates, which usually consists of residual products from agriculture, household waste, sewage sludge and food waste takes place (Berglund, 2006).

The gas formed during the production of biogas is often referred to as "raw gas" and can be used for electricity and heat production without upgrading. If the raw gas is intended to be used as a vehicle fuel, it must undergo an upgrade, which means that the carbon dioxide is removed. Biogas mainly consists of methane and carbon dioxide as well as small amounts of other substances (Meulepas et al., 2005). The content of methane in the biogas is usually between 50-70%, and the majority of the remaining part consists of carbon dioxide (Berglund, 2006) and a small amount of other substances such as sulfur and nitrogen (Meulepas et al., 2005). The ratio of the different components of the biogas depends on the composition of the substrate used in the digestion, where the structure and content of organic substances and nutrients play a significant role. (Meulepas et al., 2005).

3.2 Biogas production processes

Biogas production processes are designed in different ways, mainly depending on the properties of the substrate (Edström & Nordberg, 2004). The center of the process is the digester which can have either a standing or horizontal construction, the only requirement being that the methane gas should be able to be collected at the top of the digester and the digestion residues should be able to be pumped out smoothly from the bottom of the digester (ibid). The substrate is mechanically mixed inside the digester and there must be membrane roofs that are able to store the formed gas for a shorter time before the biogas is led out of the digester (Weiland, 2010).

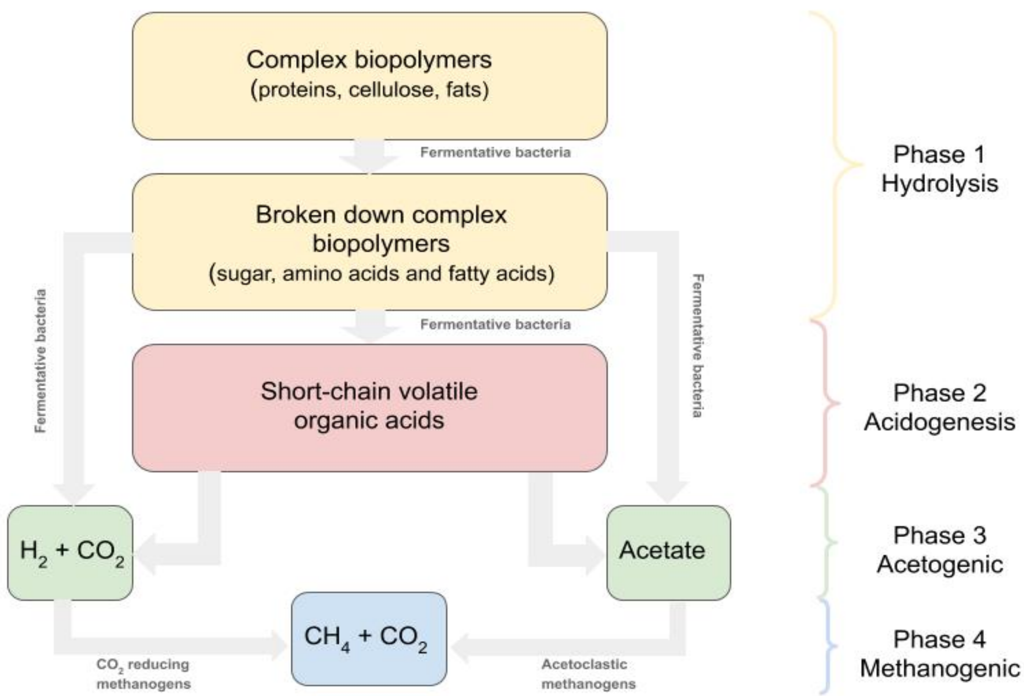

Figure 2; A summarized explanation of the digestion processes the formation of biogas (CH_4 + CO_2) based on the illustrations in Jarvis and Schnürer (2009).

All the steps in the digestion process (figure 2) are described more in-depth here below.

Phase 1 Hydrolysis

The first step in the digestion consists of hydrolysis (figure 2). Here, all the complex particulate compounds such as proteins, cellulose, fats, and hemicelluloses are decomposed by microorganisms, which then become simple and less complex compounds such as sugar, amino acids and fatty acids (Weiland, 2010; Parawira et al., 2005). The time required for the hydrolysis step is dependent on the substrate. Hydrolysis of carbohydrates can be completed in hours but lipids and protein require hydrolysis for several days. Substrates containing complex structures such as cellulose-rich materials need weeks to become degraded and even then the degradation usually does not become fully complete at the end (Deublein & Steinhauser, 2008).

Phase 2 Acidogenesis

The second step in the digestion is called fermentation (figure 2), here the simple compounds from the hydrolysis phase form hydrogen gas, carbon dioxide and acetic acid. Intermediates such as volatile fatty acids and alcohol are also formed during this step (Deublein & Steinhauser, 2008).

Phase 3 Acetogenic

In the third step (figure 2), the intermediates of step two are converted in to hydrogen gas, carbon dioxide and acetic acid (Schink, 1997).

Phase 4 Methanogenic

The methane gas is formed in this final and finishing step by using a methane generator (figure 2). The methane generator takes up the carbon dioxide and the hydrogen gas, the acetic acid which then remains are then converted in to methane gas. A large part of the energy in the organic material is transferred to the methane gas (Zhu et al., 2011).

The input of the substrate to the digester usually takes place automatically, either it is fed continuously or semi-continuously, which means that the feed is repeated several times a day (Weiland, 2010). At the same time as the new substrate is pumped, digested substrate is also pumped out to maintain a constant and optimal volume of substrate in the digester (Weiland, 2010). The digestion residue that is continuously pumped out of the digester is transferred to a fertilizer container (Nordberg & Nordberg, 2007). It is important to reduce the methane emission from the rot residue in the manure container by keeping it covered (Ibid)

In some cases, a post-digestion chamber is used where any residual organic material in the residue can be broken down (Nordell & Rönnberg, 2015). Since biogas can still be formed in the post-digestion chamber without the addition of a new substrate, it should be equipped so that the gas can be collected (Ibid). A positive aspect of using a post-digestion chamber is that it can reduce emissions from the digestate, compared to if the residue is stored and not capable to cope with the gas that is formed (Moestedt et al., 2013).

Digestion is usually done in one step, which means that the entire degradation process takes place in a single digester (Schnürer & Jarvis, 2009). The alternative to digestion in one step is digestion in two stages where the digestion is divided into two different chambers (Ibid). In the first chamber, the hydrolysis and fermentation take place, the residue is then passed on to the next chamber where mostly the formation of biogas takes place (Ibid). The two-step digestion is less common in commercial use compared to the one-step digestion because it usually requires more regulation (Ibid).

3.2.1 Wet-digestion

Wet-digestion and more specifically total blended continuous Wet-digestion is the most common digestion technique for producing biogas (Chiumenti et al., 2017; Schnürer & Jarvis, 2017). A biogas plant that uses a wet-digestion technique consists of an initial receiving part where the substrate is received and mixed in a container, a digester where the digestion of the substrate itself takes place and a subsequent storage part (Nordberg & Nordberg, 2007).

The substrates used in wet-digestion are typically pumpable and have a high water content, which means they are in a liquid form (Parawira et al., 2008; Nordell & Rönnberg, 2015). Substrates having a dry matter content below 5% is considered as an liquid substrate. The digestion is carried out with a continuous process, which means that the substrate being continuously pumped into the biogas process (Jarvis & Schnürer, 2009). This technique is most often used in sewage treatment plants. Substrates with a dry matter content of between 5-15% are handled by a semi-continuous process, like the continuous process, the substrate still can be pumped in a fairly continuous manner (ibid). Plant waste is counted as a solid substrate because it generally has a dry matter content of over 20% (ibid).

The input of the substrate is made with larger intervals and in larger portions, thus not continuously. The plant waste could be reworked into a liquid substrate by adding liquid so that a continuous process could be achieved (ibid). The digested residue that is left over after the wet-digestion process is fluid and can be used as a biofertilizer in agriculture (Weiland, 2010). Furthermore, a post fertilizer contributes to an increased mineralization of nitrogen to ammonium, which increases the quality of the biofertilizer (Nordell & Rönnberg, 2015; Moestedt et al., 2013).

A substrate's DM content is not a decisive factor when it comes to the choice of digestion technology (Nordberg & Nordberg, 2007). By pretreating the substrate, a solid material having a high DM content can be diluted with process liquid, which makes the substrate liquid, which means that the substrate is also suitable for wet-digestion (Nordberg & Nordberg, 2007).

In other words, pre-treatment of an organic material has a crucial part in the choice of digestion technology. There are various kinds of pretreatments (5.1.2.2.1), but the basic purpose is to increase the degradation of the substrate and increase the speed of the decomposition process (Nordberg, 2006). Above all, the pretreatments of a material entail a change in the structure and particle size so that the organic material will be more accessible to degradation (Schnürer & Jarvis, 2009).

The substrate used in wet-digestion does not initially have to be pumpable, solid materials such as plant material can be processed into a pumpable mass by pretreatment (Schnürer & Jarvis, 2017) described in 5.1.2.2.1.

3.2.2 Dry-digestion

Dry-digestion plants are being introduced more and more in Sweden, but at present it is mainly practiced in Germany (Schnürer & Jarvis, 2017). Generally, the substrates used in the dry-digestion process should be relatively dry, examples of materials that could be used are crops and crop residues (Chiumenti et al., 2017; Nordberg & Nordberg, 2007) which have similar properties to the park waste. The DM content in a dry substrate should be between 20-35% (Nordell & Rönnberg, 2015), it is also important that the DM content does not exceed 35% since it has been shown that the activity of the microorganisms then starts to decrease (Schnürer & Jarvis, 2017). Compared to wet-digestion, dry-digestion has the advantage of not having to dilute the dry matter before it can be digested (Schnürer & Jarvis, 2017).

When using dry-digestion, usually not as much pretreatment is needed as compared to wet-digestion, as it is easy to sort out parts that are too large for the process (Lissens et al., 2001). Furthermore, small unwanted materials such as stones and glass do not cause any problems in the process (Lissens et al., 2001)

Batch

Garage digestion is a type of dry-digestion with batch systems (Nordberg & Nordberg, 2007). A heated and gas-tight digester is fed with substrate at only one occasion, usually with the help of a tractor (Nordberg & Nordberg, 2007; Weiland, 2010). In order to maintain a good climate for the microorganisms, the new substrate fed in is usually mixed with digestion residue from the previous process, or a process fluid is circulated through the substrate (Chiumenti et al., 2017; Schnürer & Jarvis, 2017). The biogas produced is collected at the top layer of the digester (Chiumenti et al., 2017). Each garage digestion process continues for about one month, when the degradation rate begins to decrease, the digestion residue is released and replaced with fresh substrate (Chiumenti et al., 2017; Weiland, 2010). From a workload perspective, garage digestion has its tops at the beginning and at the end of the process, when material is loaded in or out of the digester (Chiumenti et al., 2017).

Continuous

Dry-digestion can be done in two different ways, batch or continuous.
In batch digestion, the substrate is re-mixed with a process fluid which is recycled through the substrate in the digester, enabling the organisms to degrade the substrate (Chiumenti et al., 2017; Schnürer & Jarvis, 2017). A continuous dry-digestion process is usually carried out with the plug flow reactor which mixes the substrate in the digester using either rotary paddles or rotating screws, these mixers also considering that the organic materials in the digester are transported forward in the reactor (Nordberg & Nordberg, 2007). Similar to garage digestion, the new substrate that is introduced into the digester is mixed with fractions from the digestate to facilitate the degradation (Weiland, 2010). The new substrate is continuously added to it from one side of the digester while digester residues are fed from the opposite side of the digester (Nordberg & Nordberg, 2007).

Bio-cells

Batch digestion in bio-cells is considered to be a slightly less optimized digestion method because it is more difficult to control the substrate via agitation (Naturvårdsverket, 2002). The collection system for the bio-cells digestion is also not as effective as for the conventional reactive digestion, it is common for air to going in with the collection, which gives a high nitrogen content in the gas (Ibid). This means that the quality of the gas is too poor to be upgraded to vehicle gas (Ibid). This technique is used to optimize the degradation and gas production of landfills (Ibid).

3.3 Digestion process

In order for a digestion of organic materials in a biogas production to be effective, it is important that the material that is digested has the right physical properties. These features will be described more below.

3.3.1 Dry matter content (DM)

The dry matter content (DM) in a material is indicated by heating the material to 105 °C so that the water content evaporates, the remaining compounds in the material after the heating indicate the DM (Carlsson & Uldal, 2009). A materials DM is an important aspect when it comes to the biogas process. If the DM content is too high, it may entail limitations regarding the treatment of the substrate through the pumps, the stirrer and the receiver system in the biogas process (ibid). A substrate with a low DM content takes up larger volumes in the digester, which means that it also is an important aspect to be considered (Carlsson & Uldal, 2009).

The DM content of a substrate can also be modified by dilution or thickening (Jarvis and Schnürer, 2009). The energy content of a substrate having a low DM are not allowed to undergo longer transports (Jarvis & Schnürer, 2009). Likewise, the economic aspect is affected when it comes to transport of the substrate, which is also an incentive to optimize the DM content in a substrate (Berglund & Börjesson, 2003). DM is stated as a percentage of the materials wet weight (Carlsson & Uldal, 2009). Materials with a DM content of over 10% are considered high and often need to be diluted with some kind of fluid to work in the digestion process. Exceptions exist for high fat materials with a high DM content, they can still function in the digestion process without having to dilute. Similarly, materials with a low DM content of 10% and below, can act as a dilute for high DM materials (Carlsson & Uldal, 2009).

3.3.2 Volatile solids (VS)

The VS content in a specific material is obtained by heating up the material to 550 °C and see what level of combustible substances it contains. In this way one can also obtain the substances organic content (Carlsson & Uldal, 2009). Out of the materials TS content, the VS content is the only thing that will and can be broken down in the digester process (Ibid). A high VS content contributes to high gas exchange per transport unit, in other words high transport efficiency. If a material with a low VS content is used in the digestion process, it is considered to result in an inefficient utilization of the digester, in other words, there will be a low gas exchange per unit volume (Ibid). Exceptions for high gas exchange in connection to high VS content, are whether the material contains plastic or lignin. Plastic and lignin gives a material a high VS content, but it does not break down in the digestion process and therefore does not contribute to the formation of biogas (Ibid).

3.3.3 Nutritional composition, C:N ratio

In a wet-digestion, a low C:N ratio (<10) indicates excess nitrogen, which can cause ammonium accumulation and high pH values. This condition can be toxic for the microorganisms during the digestion process (Wannholt, 1998). A low C:N ratio will limit the population of microorganisms, this will result in an decreasing degradation process which means that it will take longer for the microorganisms to break down the organic material (Igoni et al, 2008). A high C:N ratio (> 30) indicates an excess of carbon, which disadvantages the degradation (Wannholt, 1998). When it comes to dry-digestion, the C:N ratio can advantageously be up to 60. In normal composting, optimum C:N ratio is about 40 (pers. comm. Bramryd).

3.3.4 Biogas yield

Depending on the substrate, the chemical composition looks different as well as the structure, which affects the gas exchange (Weiland, 2010). Proteins and carbohydrates degrade faster than fat, but have a low gas yield (Ibid). Furthermore, the gas exchange is affected by the digestion technique used and the temperature, residence time in the digester and pre-treatment (Ibid). By co-digesting various substrates, it has been found that a higher gas yield can be obtained, since it gives the opportunity to optimize the composition of nutrients and the C:N ratio between the different substrates (Ibid).

The gas yield in a substrate can be calculated if you know the DM and VS content and the proportions of carbohydrates, fats and proteins in the organic material (Carlsson & Uldal, 2009). The biogas yield is different for the different components of organic materials as you can see in table 2.

Table 2: Biogas yield and methane yield for the different substrate components (Carlsson & Uldal, 2009). VS=Volatile Solids, Nm^3=Normal cubic meters.

Substrate	Biogas (Nm^3/kg VS)	Methan (Nm^3/kg VS)	Methane (%)
Fat	1.37	0.96	70
Protein	0.64	0.51	80
Carbohydrates	0.84	0.42	50

3.3.5 Mesophilic and thermophilic conditions

It is important to maintain a stable temperature in the digester, since a temperature change during the decomposition process adversely affects biogas production. In the digester, the decomposition process can occur under mesophilic or thermophilic temperature conditions (Weiland, 2010). Under mesophilic conditions, the temperature is between 35-43 ℃, the microorganisms within this ratio usually cope with temperature differences of +/- 3 ℃ (Ibid). Under thermophilic conditions, the temperature is instead higher than mesophilic, which is usually between 45-60 ℃ (Ibid). Thermophilic processes are more sensitive to temperature differences and are more adversely affected then the mesophilic conditions. However, the microorganisms in the warmer thermophilic process have higher growth, which leads to a more efficient biogas production (Ibid)

3.4 Substrate

Substrates contain organic components like carbohydrates, fats and proteins (Jarvis & Schnürer, 2009). The energy content of the various components varies, which means that the composition of the components in the substrate plays an important role regarding the amount of gas and methane content that will be generated during the process (ibid). Table 2 illustrates the relationship between the organic substrate component and the distribution in biogas and methane gas.

3.4.1 Definition of park waste

In order to identify the most common plant material that later will be relevant as park waste, Widar Narvelo city ecologist at Helsingborg city development department in was consulted. According to Narvelo, the most common park waste material was grass, meadow plants, flowers and branches / twigs. The grass surfaces are sown with grass seed mixtures from different suppliers. One of the suppliers they use is Weibulls, their grass seed mix contains Agrostis capillaris, Festuca rubra, Lolium and Poa pratensis. Furthermore, Narvelo says that Helsingborg is investing in the construction of more meadows in places where there are lawns, which can then become mowing material instead of mowed lawn. The cover for this work is illustrated by the meadow image, the meadow was created in 2016 and already the following year it is full of meadow flora (pers. comm. Narvelo).

3.4.2 Biogas exchange and degradability

In order for a substrate to be used in the production of biogas, it must be capable of being degradable in anaerobic conditions. Gas exchange is also an important aspect when evaluating a potential substrate for biogas production (Carlsson & Uldal, 2009). To test the potential of a particular substrate, a simple digestion experiments must be performed, then all the significant parameters can be evaluated in the substrate. The yield of a substrate depends on which other substrates are present in the mixture that is supposed to be digested (Carlsson & Uldal, 2009). Furthermore, the load on the system, residence time in the digester, the efficiency of agitation, the presence of inhibited substances and the content of nutrients have an important role in the biogas yield (Ibid). Furthermore, the biogas yield of different substrates is determined by the proportion of dry matter, the proportion of organic materials in the dry matter, the organic material degradability and the composition of fat, protein and carbohydrates (Ibid).

3.4.3 Co-digestion

Co-digestion means that several different kinds of organic material are digested together at the same time (Naturvårdsverket, 2012). It has been found that co-digestion usually leads to an increased methane content in the formed biogas compared to if each organic material was digested separately (ibid). One reason why co-digestion contributes to a higher content of methane is that the mixed organic materials have a better chance of containing a higher amount of important components that favor the growth of microorganisms during digestion (Jarvis & Schnürer, 2009). This is an important economic aspect because good knowledge about how different materials complement each other during the digestion can optimize and give a larger dividend during biogas production (Swedish Energy Agency, 2010). However, co-digestion processes usually require longer residence times (Jarvis & Schnürer, 2009). The Swedish Energy Agency wants biogas producers to roam for smarting their materials, but it must not disadvantage the properties of the digestion residue in such way that it becomes useful (Swedish Energy Agency, 2018).

3.4.4 Pretreatment

Due to compliance with different rules and regulations or simply to make the biogas process more efficient by increasing the availability of the substrate, the substrate may need to be processed by pretreatment before it is used, depending on its physical properties. A pretreatment is carried out with the aim of making the substrate more easily accessible to microorganisms in the digester and to make the biogas process more efficient (Bohn et al., 2010). A pre-treatment may also have the purpose of sorting out unwanted materials such as plastic and metal, it is also common to pre-treat by disintegrating the material to avoid operating problems (Ibid).

The type and amount of pre-treatment required depends on how much pollutants the substrate contains and how the waste has been collected (Hansen et al., 2007). It is important that the pollutants are removed before it enters the digester, as otherwise it can lead to operational problems or lead to that the digest residue does not meet the requirements to later be used as biofertilizer (Ibid).

Below are four different pretreatment techniques presented. To achieve optimal process conditions, a combination of these is usually applied.

Sorting

In advance sorting out materials that can’t be digested or are likely to create mechanical problems in the digestion process. If the digest residue is to be used as biofertilizer, it is important that unwanted materials are sorted out, but it is also important that not too much organic matter is sorted out (Eriksson and Holmström, 2009). Large and heavy materials need to be sorted out to avoid accumulating on the bottom of the digester and causing problems with the stirrer (Lissens et al., 2001). Sorting can be done in different ways depending on what is to be sorted out.

Five different sorting techniques:

1. *Sedimentation* - To homogenize the material, sedimentation can be carried out to separate the heavy material from the light material. The heavy material is collected at the bottom, while the light material such as plastic is collected on the surface, the intermediate fraction is the material that then goes to the digestion (Bohn et al., 2010).
2. *Sieving* - Sieving is another pre-treatment that has the purpose of removing objects that can cause problems with the micro-organisms or the process-technical part of the digestion (Nordberg, 2006). If a waste consists of materials of different particle sizes, a screen or layer can be used to sort out the materials depending on the particle size (Hansen et al., 2007). A disk screen has several parallel discs with a specifically adapted spacing and can sort out light and heavy materials such as plastic and paper from heavier and smaller materials that primarily consist of organic materials (Hansen et al., 2007). The organic material falls between the discs and is collected, while the pollutants are transported away (Hansen et al., 2007).
3. *Strainer* - Using a drum screen, paste particles can be separated from liquid. The drum screen has a drum with a screw that transports the particles out of the drum (Läckeby Water, 2011b).
4. *Screw Press* - If a material contains large amounts of unwanted material, a screw press is used. The screw press consists of a cylinder with small holes in it, through which organic material, which mainly consists of liquid and small particles, is sorted out, this material then goes to digestion (Hansen et al., 2007). Instead, the unwanted material such as plastic, paper and metal is passed through the cylinder (Hansen et al., 2007).
5. *Magnetic separation* - If a material is at risk of having metal fractions in itself, a metal separation may be needed, this is to ensure that the mechanical part of the digestion process is not to be damaged and to avoid pollution in the digestion residue (Moberg's process control AB,

2011). The technique is that magnets capture and collect magnetic materials (Moberg's process control AB, 2011). For a magnetic separation to be able to function optimally, the material being treated should be of high quality, that is, the content of other pollutants, such as plastic, may inhibit the pretreatment (Hansen et al. 2007).

Thickening/dilution

Pre-thickening is used to increase the dry matter content of the substrate by removing the water by pressing it out through a press (Jarvis & Schnürer, 2009). Plant material as substrate instead needs to be diluted by adding water or be mixed with a substrate with high water content, in order to obtain optimal properties for example wet-digestion (Jarvis & Schnürer, 2009; Weiland, 2010). In connection with the dilution, an homogenization is usually performed on the substrate, the goal is that as much organic material as possible should be able to dissolve with the liquid and make it more easily accessible to the microorganisms (Bohn et al., 2010). A good homogenization means a decrease in particle size which can be carried out by means of a cutting pump (Ibid).

Reduce particle size

By decomposition of the material reduces the risks of mechanical problems and the substrate becomes more easy to handle for the microorganisms (Bohn et al., 2010). This is the most common method of pretreatment of substrates, making the organic material more accessible to the microorganisms and benefits the gas production. The potential gas exchange does not increase, but leads to a faster digestion process which benefits the economy of the biogas plant (Jarvis & Schnürer, 2009). Depending on the composition of the substrate and the chemical structure, there are various ways of decomposing. The substrate can be mechanically decomposed by means of, for example, a mixer or a mill, furthermore there are thermal, chemical and biological methods for decomposition (ibid).

Hygienisation

It is primarily for biogas plants that handle animal materials that need to undergo hygienisation (Jarvis, 2012). If the substrate is at risk of containing infectious agents a hygienization is performed by heating the substrate at 70°C for one hour. This is primarily done in order for the digestion residue to be used later without risking the spread of infection (Jarvis & Schnürer, 2009).

Alkaline pretreatment by chemically removing CO2 and H2S, which is formed during the digestion process, using 3M NaOH, has been shown to favor the gas exchange. Alkaline treatment increases the availability of the enzymes by dissolving the structures of the biomass, which facilitates the enzymes to break down the biomass (Paulsson et al., 2015). Furthermore, it also advocates a free passage for the methane gas to pass the treatment unaffected (Ibid). However, it can be noted that the gas yield is quite low for park waste, which has been proven in other lignocellulosic biomass during digestion (Ibid).

In other parts of the study, it has been found that the alkaline pretreatment contributed to a decrease in methane yield (Paulsson et al., 2015). This could be explained by the fact that plant mass has a protection which has the purpose of protecting against microbial attack, these protective mechanisms may have affected the digestion process (Paulsson et al., 2015; Wikandari et al., 2013). This applies primarily to coniferous biomass containing raisins and terpenes, these substances have been shown to have an inhibitory effect on the microorganisms in the biogas process (Wikandari et al. 2013). The alkaline pretreatment may have contributed to the inhibitory effect of the microorganisms by contributing to the release of the active substances (Paulsson et al., 2015).

Compared to pumpable liquid substrates, substrates with high solids content will generally need to be pretreated before being digested. A pretreatment can be costly, depending on the extent, which affects the value of the substrate. (Jarvis & Schnürer, 2009).

Heat needs to be continuously added from the outside to keep the process temperature at a constant level. In order for the microbial activity at the digestion to work, a certain temperature is needed. Large-scale digestion occurs either mesophilic, which is usually around 35C or thermophilic between 50-55C (Meulepas et al., 2005).

3.5 Collection and management of park waste

3.5.1 Responsibility

Helsingborg city administrations are responsible for the city's green areas and employ contractors for its care (Renhållningsordning Helsingborgs stad, 2016). In this case Peab plant AB and Green Landscaping AB collect the park waste in Helsingborg (pers. comm. Lindkvist). Each district council decides how the park and garden waste is to be taken care of and treated according to the districts different conditions. The park waste is composted or incinerated (Renhållningsordning Helsingborgs stad, 2016).

At present, the city of Helsingborg try to reuse the park waste at the places where they occur by, for example, blow in leaves in shrubs and flower beds. But it is not always suitable for the more esthetic fine urban parks or in places where leaves can easily fly around and gather in piles at inappropriate places (pers. comm. Green; Lindkvist; PEAB). The contractors collect all park waste using cars and trailers. There are also opportunities to chop down larger waste in place using a chip car which then transports the chips away (pers. comm. Green landscaping; Lindkvist; PEAB).

Weeds and residues from the cutting of perennials and shrubs are collected. The material that can be collected by the contractor is transported to an internal collection point. Coarser rice, branches and logs, on the other hand, can be sold for chipping or producing chips of it themselves (pers. comm. Green; Lindkvist; PEAB). Another option is to leave the park waste at the recycling center at NSR in Helsingborg, where you can find out the weight of the waste you hand in, because you pay by weight for the waste submitted (pers. comm. Green; Lindkvist; PEAB). During the winter, crops of both trees and shrubs are produced, which gives rise to a waste consisting of rice and branches, as well as a small amount of leaves (pers. comm. Green; Lindkvist; PEAB).

Elisabeth Lundkvist at Helsingborg city administration also says that large amounts of seaweed are collected along the coastline in Helsingborg, the largest part of the submitted seaweed will later during the winter be returned to the sea but some seaweed is transported and left on the recycling center. The latest figures says that the weight of the submitted seaweed waste gave raise to an amount of 1500 tonnes/year, but it is important to note that the figure not only includes seaweed but also large amount of sand and stones (pers. Comm. Lindkvist).

3.6 The biogas market/use

3.6.1 Existing biogas plants in Helsingborg

There are three gas stations for biogas scattered in Helsingborg (Biogas2020, 2017). In a study where Swedish municipalities' potential for biogas was investigated, Helsingborg was pointed out as the municipality with the greatest potential with an energy amount of 7 GWh per year (Stjärna, 2014). In 2016, 438.7 GWh of biogas was produced in Skåne from 47 different plants (Biogas Syd, 2018).

3.6.2 The situation today

Biogas is most common used as vehicle gas and to heat production. When the biogas is to be used as a vehicle gas or supplied to the natural gas network, purification from particles, corrosive substances and water is required, as well as increasing the energy value by removing carbon dioxide (Swedish Energy Agency, 2018). The purification process is called upgrading, and can be implemented with different cleaning techniques in an upgrading plant. When biogas are upgraded, it contains about 97 percent methane and then only 3 percent carbon dioxide and nitrogen gas (Ibid).

To generate heat during heat production, the gas is burned in a gas boiler. The heat can, for example, be used to keep the temperature at the right level in a digester and further heat up tap water and premises (Swedish Energy Agency, 2018). Furthermore, the biogas can also be used to produce heat and electricity in cogeneration plants. The electricity efficiency of the internal combustion engines in CHP plants is usually 30-35 percent (Ibid).

If biogas is used as vehicle fuel or fed into the natural gas grid energy content must be raised. Therefore, the biogas is purified on carbon dioxide and will then consist of 97 percent methane and is then called the biomethane. The energy content of the biomethane is 9.67 kWh/normal cubic meter compared to pure methane which has an energy content of 9.97 kWh/normal cubic meter. Propane must then be added to the biomethane before it can be used in the natural gas network, because natural gas has an energy content of 11 kWh/normal cubic meter (Energigas Sverige, 2018).

In a socio-economic analysis of the biogas's benefits in Skåne, published by Anderson et al. (2018). The result are based on the biogas produced under 2016 in Skåne, and was completed by adding the value of four different aspects; reduced greenhouse gas emissions and air pollution, the value of biofertilizer and the value of energy security. The result was presented in numbers of money and the socio-economic benefit of biogas production in Skåne amounts to a value of 278.4 million SEK/year (Anderson et al., 2018).

4. Goals and regulations

4.1 EU goals

The European Union (EU) directive just accepted an updated Renewable Energy Directive, RED II, and the basic purpose is to mandate over the use of renewable energy within EU. The directive requires that 32 % of all the consumed energy in EU should be renewable. In this newly updated RED directive now include a transport sub-target, which means that all the member states must demand that the fuel suppliers provide a minimum of 14% renewable energy of the total amount of fuel used by road and rail traffic by 2030, to be able to cut the carbon dioxide emissions (RED II; European parliament, 2019).

Furthermore, the EU has set the goal to 2030 to reduce the greenhouse gas (GHG) emissions by 40 % compared to the levels in 1990 (European Commission, 2014). By 2015, all EU Member States had managed to reduce the GHG emissions by 24% (European Environment Agency, 2017). During the same period, the transport sector, which accounts for approximately 20% of the total GHG emissions in the EU, has instead increased by 16% (Ibid). In order to reach the EU target by 2030, one must focus more on reducing emissions in the transport sector by using more sustainable fuels.

4.2 National goals Sweden

The goal of the national Swedish energy policy is to secure the supply of electricity and other energy with competitive terms in both the short and long term (Energigas Sverige, 2018). The energy policy must create conditions for an efficient and sustainable energy use with a low negative impact on the environment, health and climate, and furthermore it should facilitate a transition to a more ecologically sustainable society (Ibid). Since January 2018, Sweden has acquired a new climate policy framework, the goal is that by 2030 biogas use will achieve 15 TW hours annually (Ibid).

In the summer of 2017, the Swedish parliament approved a new national climate policy. For example, this policy includes the goal of net zero GHG emissions in Sweden by 2045 (The Government of Sweden, 2017). One objective is that the emissions generated by domestic traffic in Sweden, apart from aviation, should decrease by 70% by the year of 2030 compared to the 2010 emission quantity in Sweden (Trafikverket, 2016). To achieve these goals, several measures need to be combined, one must above all work to reduce the need for transport and furthermore, one needs to increase the use of biofuels and electricity as fuel and improve energy efficiency (Ibid).

In Sweden, a new political instrument (Lag 2017:1201) is being implemented that aims to reduce GHG emissions. It implies that fossil fuel suppliers will reduce GHG emissions by a certain percentage each year by gradually incorporating renewable fuels into the fossil fuel (Lag 2017:1201).

Each and every EU Member State must also comply with the mandatory target of having 10% sustainable car fuels in the transport sector by 2020, according to Directive (2009/28/EC). According to the current EU policy (Directive (EU) 2015/1513), the actual production of biofuels in new plants must also be sustainable. More specifically, this means that the production of biofuels must release 40 % less GHG than what vehicles with fossil fuels emit or 33.5 g CO2eq MJ^{-1}.

The EU policy (Directive (EU) 2015/1513) also focuses on reducing the use of crops as a substrate for the production of biofuels. It is only allowed for the EU Member States to use a maximum of 7 % crops for the total biogas production, one reason being that otherwise the mandatory target of 10% sustainable fuels might be difficult to achieve. Another reason why crops should not be used as a substrate in the production of biofuels is because of the concern that it may lead to changed land use, which may further lead to increased emissions of GHG. The policy also wants to highlight and see an increase in the use of waste as a substrate. The green material from the park areas in Helsingborg city is considered a waste, as there is currently no use area for it after mowing.

4.2.1 The waste hierarchy

Biogas production is an effective way of utilizing the waste of society and making it into useful and environmentally friendly products such as biogas and biofertilizer (Energigas Sverige, 2018). In the Swedish Waste Directive 2008/98/EG agreed by the EU in 2008, they describe the waste hierarchy as a priority for legislation and policy on waste (figure 3).

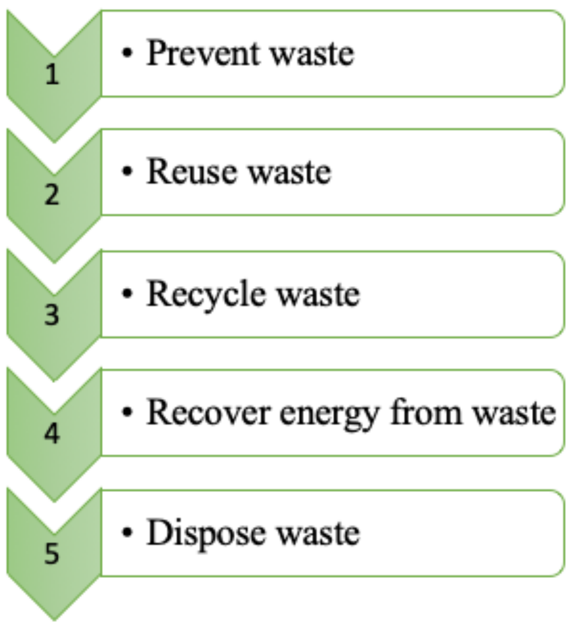

Figure 3; Illustration of the waste hierarchy based on the provisions of the Waste Directive (2008/98/EC).

4.3 Local and regional goals in Helsingborg and Skåne

It is mainly three pieces of control documents that are important in Skåne; Energy and climate strategy for Skåne 2018, Region Skånes environmental strategy program and Regional Development Strategy (RUS).

Energy and climate strategy for Skåne 2018 is an overall governance document for all public organizations in Skåne conducted by the county administrative board, Region Skåne and the municipalities in Skåne. The new climate and energy strategy in Skåne has been developed by "The Climate Cooperation Skåne" which is a collaboration platform for the Municipality of Skåne, Region Skåne and the County Administrative Board in Skåne County. The strategy will serve as guidance and support for developing and implementing measures to reach Skånes climate goals. All local and regional operations in Skåne should be able to use the strategy in their operations (Kommunförbundet Skåne, 2018).

Biogas is a prioritized target for Skåne according to (Kommunförbundet Skåne, 2018) and is included in basically all of the set performance areas in the strategy. The majority (48 %) of the biogas has been upgraded to vehicle fuel and 44 % have gone to heat production (Ibid).

Region Skånes environmental strategy program, governs much of the development within Skåne. The program aims to integrate environmental aspects into all areas of activity and development work within Skåne County. It should be a political steering document which should be guided through priorities. In this program, Skånes agenda for biogas is taken up, where the goal is that Skåne will become Europe's leading biogas region in 2030 (Region Skåne, 2017). In Skånes agenda for biogas, one will become Europe's leading biogas region until 2030 by developing technology and knowledge within substrates, processes for the production of renewable methane, infrastructure, market and area of use (Region Skåne. 2015).

Regional Development Strategy (RUS), is very comprehensive and serves as an umbrella over the two previous governance documents. RUS has been created to give a broad consensus on a common target image for Skåne until 2030. It will strengthen cooperation between the actors in Skåne where biogas conversion is mentioned (Region Skåne, 2014).

The County administrative boards Skåne together with Region Skåne and the Municipal union Skåne have produced a policy document "Climate and energy strategy for Skåne 2018". In this document, all the regional objectives and prioritized areas of action are stated. One of the goals is to reduce greenhouse gas emissions in Skåne by 80 % 2030, compared with the amount of emissions in 1990 (Klimatsamverkan Skåne, 2018). An increase in biogas production and consumption is included in the objectives and aims to contribute to the greenhouse gas emission goal. In March 2015 the regional development committee adopted the goal that Skåne will become Europe's leading biogas region in year 2030 (Ibid).

The website skanesmiljomal.info (County Administrative Board Skåne, 2019a) presents evaluations of whether the national environmental goals will be achieved in Skåne county. The environmental goal that have the most significant connection to biogas are "Limited climate impact", the objectives will not meet the targets set for 2030 in Sweden (County Administrative Board Skåne Skåne, 2019b). Greenhouse gas (GHG) emissions have decreased by 33 percent between 1990 and 2016 in Skåne, as a result of halving emissions from energy supply (Ibid). Furthermore, emissions from transport have decreased by 14 percent during the same time period, but the consumption of imported products is causing an increasing of GHG emissions (Ibid).

5. Analysis and result discussion

5.1 Description of approach

Further in this following chapter, the result from the interviews will be presented in the form of tables. The literature primarily used in this chapter is mentioned in the previous chapters (4 & 5) therefore, reference to these previous chapters will be included in this chapter. Additional literature was also used in this chapter to strengthen the information received from the interviews. These results will be followed by an analysis and result discussion.

The conclusions were then drawn from these discussions as well as from own proposals for possible future practical experiments. The structure is based on the three main questions in this study as well as on the sub-questions related to them (1.4).

5.2 The possibility in using park waste

Table 3; Compilation of the overall answer of the respondents. The questions asked in the interviews is to be find in Appendix 1,2,3, and these questions are then sorted under the sub-questions regarding the first question in this study "Can residual products from the green park areas in Helsingborg be used as a substrate in biogas production?".

Sub-questions	**Responded by**	**Summarized answer**
Is there a will/interest in using residual products from the green areas?	Respondent group 1 characterized by 7 respondents knowledgeable in the biogas field (table 1)	There is a desire to know more about park waste as a substrate for biogas production among the respondents. They all mentioned that this goes hand in hand with the national and regional goals regarding biogas, climate and environment.
Is it technically feasible?	Respondent group 1 characterized by 7 respondents knowledgeable in the biogas field (table 1)	Respondents believe that new technology will be needed to be able to use park waste as a substrate in biogas production.
Is it economically feasible?	Respondent group characterized by 7 respondents knowledgeable in the biogas field (table 1)	The respondents estimate that park waste as a substrate will entail a higher cost related to pre-treatment and transport / collection.
Are there any political incentives?	Respondent group 2 characterized by 4 respondents knowledgeable in the local and national goals and regulations (table 1)	Respondents argue that increased production of biogas as a result of a new source of substrate goes hand in hand with Sweden’s, Skåne’s and Helsingborg’s climate and environmental goals.

5.2.1 Willingness/interest

The majority of the respondents from the interviews have heard of the concept of producing biogas from plant material. Since the respondents are active in the field of biogas in Skåne, several have heard of various development projects in the biogas area in Skåne where, among other things, park waste has come up. It seems that there are some small-scale biogas producers in Sweden who have tried the concept, but it is unclear what the result of it was (Table 3).

Respondents who are active within the biogas business and/or work with the regional targets related to biogas production and targets regarding this within Skåne, describes that Skåne are having ambitious goals aimed at reducing energy consumption and increasing the share of renewable and reducing CO2 emissions (Table 3). It is mainly three different control documents that are important in Skåne. *Energy and climate strategy for Skåne 2018*, works as an overall governance document for all public organizations in Skåne (county administrative board, region Skåne, municipalities). *Region Skåne's environmental strategy program* governs much of the development within Skåne. *Regional Development Strategy* (RUS) is very comprehensive and serves as an umbrella over the two previous governance documents.

Furthermore, the respondent highlighted that the biogas itself has an important role in the circular economy within Helsingborg. By making use of the local organic waste materials and to produce biogas of it, can generally be considered to contribute positively to the local circular economy, which will be more vital to work with within the next few years they said. It is important to take advantage of our resources and begin to see waste as a resource, which is what if park waste is used as a substrate regarding to the waste hierarchy (Figure 1). The respondents also believe that renewable fuels are needed in both the traffic sector and the energy sector. Even though some do not see any huge potential in the park waste, it still contributes to increased biogas production.

Several respondents argue that there will be a higher market value by producing biogas instead of directly composting the park waste. If the park waste would be burned or composted as it is today (pers. comm. Lindkvist), one disturbs the nutrient cycle and destroys the nutrients to a polluted ash. And that the park waste consists to a large part of the wet material, which takes energy from the combustion but is needed in a wet-digestion.

What mainly speaks against the use of park waste as substrate is the portion of the waste park consisting of woody materials (table 3). The woody material such as shrub and tree parts cannot be digested in a plant for wet-digestion without first having been pre-treated (3.4.4). In Helsingborg there is no dry-digestion plant that would be needed to be able to digest the woody part of the park waste.

To meet the goals under chapter 4, Skåne's biogas market need to increase, that is, production and demand for biogas must increase locally (Helsingborg city, 2018). If the demands for biogas in the future increase, Helsingborg will be forced to find new sources of substrate. This is where park waste potentially will be able to enter and supplement the original substrates.

5.2.2 Technical feasibility

Some materials are more suitable than others for the production of biogas, process parameters such as, temperature, load and retention time have a great influence on how effectively a substrate can be broken down (Jarvis & Schnürer, 2009). Pre-treatment of the substrate also has an effect on the biogas process, whether the material is used alone or together with other materials in a mixture (Ibid). Materials containing toxic substances or lignin cannot be broken down during the biogas process, which also has an impact on the quality of the biogas (Ibid).

It has been found that a good sorting of plant material generally leads to a higher biogas exchange compared to if one carries out chemical pretreatment of the materials before the digestion (Paulsson et al. 2015; Triolo et al. 2012). In the study conducted by Paulsson et al. (2015), the present suggestions on the possibly simplest way to improve gas exchange on, among other things, park waste, where more accurate sorting of park waste is the central part. The sorting involves sorting out the biomass that is considered to be easily digested with a low content of lignin cellulose, such as grass, fruits and flowers, so that it can be treated individually.

Just as mentioned in the technical background (3.4.4), the respondents believe that it will be necessary to add large amounts of water to the woody park waste and splinter it down to small fractions so that it can be used in a wet-digestion plant (table 3). However, grass and flowers will not need more pretreatment than other substrates because lawn mowers already disintegrates it to a useful size, then it is necessary to solve the logistics in order to streamline the transport from the location of the material to the biogas plant (table 3). As mentioned in the technical background (3.2 & 3.3), different substrates will need to be handled differently depending on their specific composition. There is a study where they tried to use alkaline pretreatment on softwood pain, which resulted in an improvement in the biogas yield of the material by over 100% (Salehiana et al., 2013). So with the right handling, and primarily the right pretreatment, the more difficult woody fractions in the park waste could also be used as a substrate in biogas production.

In order to benefit the biogas potency and fuel value, it is important to be able to effectively manage and sort the park waste (Paulsson et al., 2015). It is proposed to distinguish between the soft (grass, flowers, leaves) and the hard (woody material) fractions of the park waste to more effectively sort out the raw materials that are best suited for biogas production (Paulsson et al., 2015). The soft fractions have been found to be best suited for biogas production compared to the hard woody fractions (Paulsson et al., 2015). Generally, the respondents believe that they will need to sort the park waste into a soft fraction and a woody fraction where the soft fraction will be used in wet-digestion and the woody part must be digested in a dry-digestion plant.

It is known that inhibitory substances in plant material can affect the digestion process negatively (Paulsson et al., 2015). However, it has been found that a mixed digestion culture in digestion chambers, which controls the digestion, has an ability to adapt after being exposed to a substrate for a long time (Paulsson et al., 2015). According to Paulsson et al. (2015), this adaptation will probably take place for park waste that has a similar composition and which is digested for a long time. The mixed digestion culture will adapt and get a so-called metabolic memory, which means that it now can manages to handle inhibitory substances that are supplied together with the organic herbal park waste more efficiently (Paulsson et al., 2015).

It is well known that in the summer months it is more green in Sweden. Therefore, a conclusion can be made that there will be more park waste in the spring, summer and autumn when parks and meadows must be cut. Compared to the winter months when vegetation in Sweden goes into hibernation. This will give an uneven flow of park waste, which means that a biogas plant must have other substrates to rot and not only a digestion of park waste. However, it could be an alternative to fill up the volume during the winter with seaweed mentioned in section 3.5.1 during the winter. As mentioned in section 3.4.3, it can sometimes be an advantage to co-digest two different kinds of materials. Which in this case may be what will be needed.

Mechanical problems

According to Paulsson et al. (2015) and their testing of three different digestion techniques with packaging waste, a batch digestion resulted in the highest methane yield. Dry-digestion and two-stage digestion need to take place in larger scales to produce a positive methane yield (Paulsson et al., 2015). The dry-digestion showed problems during the first part of the digestion phase, due to the presence of rapidly degraded substances which formed volatile fatty acids which reduced the pH content of the digester (Ibid). This causes the methanogenic organisms to stop being active in the process (Ibid). An extensive reduction of pH in the digestion process can lead to the entire process having to be interrupted and restarted (Ibid).

Through interviews in a study conducted by Björkmalm (2013) where a mapping of existing technical and process-related problems in co-digestion plants with pretreatment was carried out. The result showed that the pretreatment of the biogas plants was the biggest problem. It was also difficult to sort out unwanted materials from the substrates, such as plastics, which caused either operational problems or large quantities of organic digestible material with the undesirable materials in the sorting (Björkmalm, 2013). A large amount of plastic could also be found in the digestion residue (Ibid). The respondent in table 3 also expressed a concern that the park waste can contain debris such as plastic bags and aluminum cans that also will be needed to be sorted out. There are four different pretreatment techniques listed in 3.4.4 that could sort out plastics from the material.

Co-digestion

Respondents (table 3) were a bit uncertain whether it would be technical, chemical, mechanical and process-feasible to mix park waste into already existing production. Mostly because different materials need different periods of time to be fully broken down, then you also want to strive to have as homogeneous substrate as possible in order to avoid changing the composition in the meantime. A digestion process should run smoothly and a mix can impair the efficiency of the process. But if the different materials with properties that fit or favor each other in the digestion process, co-digestion can be positive (3.4.3)

More dry-digestion plants will open up for digestion of more equitable materials such as the woody park waste. New technology will be developed and the Swedish Energy Agency in Sweden are financially supporting several projects concentrating on dryer digestion techniques (Swedish Energy Agency, 2017). There is one known dry-digestion plant in Mörrum Sweden which opened up in 2013 (Ibid). The plan have however encountered problems with unwanted materials, something that they are currently work on soleving with a megnetic separator (3.4.4) that will extract the materials that now interfere with the process. Also, the protein-rich substrate has been causing ammonia inhibition of the process, which making it an unfavorable environment for microorganisms (3.4.4).

5.2.3 Economic feasibility

Respondents in table 5 are skeptical about whether there will be a future for park waste within biogas production, mainly due to the financial aspect. The respondents (table 3) also believe that the costs will primarily be related to transport, collection/sorting and pre-treatment of the park waste. Which generally, without the respondents (table 3) doing any calculations on it, are believed to be more expensive for park waste compared to the substrates that are commonly used today (food waste and manure).

If a biogas system is considered to be financially feasible or not, can be compiled by adding together the costs and income from the production versus the potential income from the biogas and the digestion residue (Börjesson et al., 2016). Also, costs related to biogas production that should be taken into account when deciding whether it is economically feasible or not is the costs for operation and maintenance of the plant, associated capital cost and investments in the biogas plant, process energy, raw material cost (Ibid). In addition to the above mentioned aspects, the properties of the raw material and the speed of biogas production also affect the total production cost (Ibid).

The respondents who did not consider that the costs will rise during the use of park waste as a substrate mean that one creates a refined product from a residual product. Even though in the wet-digestion, the respondents believe that more steps will be needed in forms of pretreatments, but in dry-digestion it is not believed that more steps will be needed if one looks at the woody material. Grass and flowers will generally not need more steps in any of the digestion techniques according to the respondent in table 3. It can be seen that one has access to a cheap raw material, and that it is a prerequisite for ultimately being able to produce cheap and competitive biogas. It will also benefit a local and regional bio-based circular economy.

It is common for biogas plants to charge a fee for receiving biogas substrates, depending on the substrate (Westman et al., 2014). The reason why the owner of the substrates sometimes has to pay the biogas producers are because of the owner also has to pay for the alternative handling of the substrate (Ibid). Examples of substrates that go under this category are manure from animals, sorted organic waste and certain industrial waste (Ibid). As a rule, the receiving fee is also higher for solid substrates that cannot be pumped before processing (Ibid).

Reception fees are based on rough estimates from the biogas producers websites page conducted by Westman (2014). Examples of fees that the recipient, i.e. the biogas plant, can charge are:
SEK 0-200 / ton pumpable substrate recalculated SEK 0-0.05 / kWh.
SEK 300-600 / ton non-pumpable substrate recalculated 0.08-0.15 SEK / kWh (Westman, 2014).

Exceptions to the recipient fee may sometimes apply to substrates with high gas yield (Nm^3 gas / ton of substrate), because the substrates are often demanded by the biogas producers (Westman et al., 2014). Examples of a substrate with high gas yield are slaughterhouse waste. Due to high demand, the price of these substrates can exceed to above SEK 2000 / ton and in this case it is not the owner of the substrate that pays to get rid of it, but they can now sell it instead (Ibid).

Since park waste is considered to have a low gas exchange (Paulsson et al., 2015), the costs will mainly be at Helsingborg city that collects and probably will have to pre-treat it in order for it to be attractive as a substrate. On the other hand, substrates containing animal byproducts (ABP) must be processed by hygienists before it is digested to avoid the spread of infection (Westman et al., 2014), since it is statutory in the EU and in Sweden (Jordbruksverket, 2018). Hygiene will entail extra costs, which can be considered unattractive (Westman et al., 2014). And these are costs that park waste will not have to take into account.

<u>Competition on prices</u>

90 % or more of the biofuel consumed in Sweden today are imported (Swedish Energy Agency, 2017). The interest in biofuels is increasing among other countries around the world, which leads to an increased competition regarding the biofuel that Sweden imports (Lantz et al., 2018). This indicates that Sweden in the future potentially will find it more difficult to maintain the national demand for biofuels. This also indicates that the demand for domestic production of biofuels will increase in Sweden (Lantz et al., 2018). Because Skåne is located near Denmark and the locally produced biogas from Skåne compete with the double subsidies biogas from Denmark, one subsidy on the production from Denmark and one tax deduction from Sweden (Government Offices of Sweden, 2018). It means that the Danish biogas are much cheaper than the Swedish biogas.

This is significantly noticeable in Skåne, since biogas can easily be transported from Denmark via the western Swedish gas network, to which several of Skåne's gas users are connected to (Anderson et al., 2018). The subsidized and cheap biogas imported from Denmark can disadvantages Skåne's biogas market. Therefore, it is important to find new local solutions to strengthen the biogas market and it is also important that all actors within the biogas production cooperate and try to control the biogas market to get provision for the local / regional biogas.

Dry-/wet-digestion

From a cost perspective, wet-digestion and dry-digestion are considered to be equivalent (Lissens et al., 2001). A wet-digestion process uses pumps and pipes that are cheaper than the dry-digestion process because dry substrates often needs to be handled with more powerful pumps (Ibid). However, larger reactors and usually more expensive pretreatments are needed for wet-digestion (Ibid).

Transport and logistic

Table 4; Compilation of the overall answer of the respondents regarding transports and logistics of the park waste. The questions asked in the interviews is to be find in Appendix 5.

Overall questions	Responded by	Summarized answer
Is it feasible logistically to use park waste as a substrate?	Respondent group 5 characterized by 2 respondents knowledgeable in transport and logistics (table 1)	From this perspective, there are some barriers but it is still feasible. There would be a need for modifications to facilitate the transport chain, such as, for example, pre-processing the park waste in place with a machine and driving it directly to the digestion plant. In order to contribute to maintaining / increasing demand for biogas, it is also important that the vehicles that transport the substrates go on biogas.
Are there any logistical obstacles related to the transport / collection of the park waste?	Respondent group 5 characterized by 2 respondents knowledgeable in transport and logistics (table 1)	The obstacles are mainly related to the fact that the volume varies during the year, the collection at present involves many short haulage routes and the sorting of different fractions within the park waste must be improved.

The respondents in table 4 believed that the actual logistics is an important aspect regarding park waste, they believe that it will be a need of sorting the park waste. Furthermore, the respondents believed that there is a need to streamline the transport from the origin of the waste to the sorting station, likewise for the possible pre-treatment and then to the biogas plant. Costs will then depend on how efficient this logistics chain is, they believed (table 4).

According to the respondents experience of substrate (table 4), food waste will require a mechanical pre-treatment and be picked up with refuse trucks with multi-compartment vessels or the like, which are then transported by garbage truck to a pretreatment plant which is often linked to the biogas plant. Liquid substrate such as fertilizer or slaughterhouse waste is transported by tanker. Park waste involves handling of dry material (3.4.1), which leads to a different handling chain, at least until it can be pumped. It is also important to be able to reload and sort the park waste (table 4).

5.2.4 Biogas production compared to composting

The respondents in table 4 considered to be more profitable to produce biogas from the park waste than to compost it, both in terms of the nutrient cycle and the climate. The digestate that are produced as a byproduct can then be used as a biofertilizer (Weiland, 2010). Park waste will also have a higher socio-economic value if it is used as a substrate in biogas production compared to composting, because the organic material can generate renewable energy (Garcia Perez, 2014). In composting, a soil is formed which can then be used for planting (Odlare, 2007).

The nutrients in biofertilizers that are formed during biogas production have been found to be more accessible to plants compared to the soil formed in a compost (Odlare, 2007). During the biogas production, the methane gas that is formed can also be utilized, therefore the biogas production can be considered better from a socio-economic perspective.

5.3 Most suitable plant materials

Table 5; Compilation of the overall answer of the respondents. The questions asked in the interviews is to be find in Appendix 1 & 2, and these questions are then sorted under the sub-questions regarding the second question in this study "Which plant materials from the park waste are suitable for use in the biogas production?".

Sub-questions	**Responded by**	**Summarized answer**
Which fractions of the park waste are suitable for use in the production of biogas?	Respondent group 3 characterized by 3 respondents knowledgeable in biogas production (table 1)	Green and juicy materials are suitable for the existing wet-digestion plants and all park waste material can be used within a dry-digestion plant according to the respondents.
What kind of production technique are the most efficient?	Respondent group 3 characterized by 3 respondents knowledgeable in biogas production (table 1)	For park waste, the respondents mean that a dry-digestion is best suited.

5.3.1 The suitable park waste fractions

The respondents in table 5 definitely believed that there is a potential in using park waste as a substrate. The respondents in table 5 describe the optimal substrate for biogas production as a substrate that is energy-rich, easy to handle, easy to pump in the digester and have a high gas yield. The park waste should contain juicy material where you can squeeze out carbohydrates, starch, proteins to fit a wet-digestion. The substrate should not cost to receive and the best thing would be if the facility could get paid to receive it. They also think it is important that the substrate does not contain contaminants where plastics are the most common and examine the levels of heavy metals, especially for the plants that are collected at the roadside, since the digestion residue must be clean in order to be used as a biofertilizer (respondent table 6).

Based on a study conducted by Björnsson et al (2016), where differences in properties between different substrates were investigated, one could see that the methane content of grass was slightly less than for biogas production of manure or manure + waste (table 6). Furthermore, grass as a substrate could contribute to a higher proportion produced biogas and a higher proportion of upgraded biogas compared to manure as a substrate (table 6). In this case, the grass had a high DM content compared to other substrates, which can be considered unfavorable (3.3.1).

Table 6. The results of the process conditions from biogas production of different kinds of substrate from a study conducted by Björsson et al. (2016).

	Unit	**Manure**	**Grass**
Feedstock addition	Kg	55055	14014
Feedstock DM	%	7.6	33
Biogas production	m^3/h	157	267
Biogas to upgrading	m^3 /h	132	224
Methane content	%	60	55
Upgraded methane	m^3/h	79	123

Food waste generates 162 tones substrate to the biogas production in Skåne every year (County Administrative Board Skåne, 2011). In the future, food waste will probably decrease both privately, in food stores and restaurants with today's increasingly environmentally conscious lifestyles

(Naturvårdsverket, 2012). This probably means that the volume of substrate based on food waste potentially will decrease in the future. It is necessary to find new substrates that can cover the loss of others. Park waste could potentially become a substrate that does so, as it also contributes to the local and regional circular economy.

Protein is found in the highest amount in shrubs and trees (Bate Holmberg, 2018) and, in particular, plant annuals. Carbohydrates are found mainly in plant starch and especially in the roots (Leijonhufvud, 2014). Proteins are known to degrade fast bud instead having a low gas yield (3.3.4). Leaves, shoots and stems usually contain proteins along with vitamins and minerals (Grzeszczuk et al. 2016). The most energy-rich plant material is flowers that usually contain all the three most important components of protein, carbohydrate and fat (Grzeszczuk et al. 2016). These components are important from a biogas yield perspective (3.4.2). The digestion of straw from agriculture has shown poor results on gas yield due to its high content of lignin (Carlsson, M. & Uldal, M., 2009).

Lignin is a substance that is difficult to break down and therefore takes longer to break down in the digester (Lehmann & Joseph., 2009). Similar straws have a high lignin content in woody materials (Wang et al., 2015), which can then also be considered unfavorable for use in biogas production. As mentioned in 3.4.1, Helsingborg is working to promote species diversity, they do this by building meadows on lawns. The meadow flowers establish quickly, which is favorable for the biogas production from park waste because flowers are considered the best fracture to digest.

5.3.2 Most efficient production technique

For wet-digestion, the respondents in table 5 consider that flowers and green and juicy plant parts are best suited. In a dry-digestion the respondents in table 6 believed that basically all park waste fractions can be included. The green parts of the waste are easier to digest and will require less mechanical and chemical pretreatment than the woody waste in both wet- and dry-digestion processes (3.2). The ideal would be if Helsingborg chose to build a new biogas plant capable of dry-digestion.

According to Jarvis & Schnürer (2009), plant material can be difficult to break down due to the content of cellulose and lignin and a strong fiber structure which contributes to a reduced area where microorganisms can attack during the digestion. In order to increase the degradation of plant material, the particle size should be reduced or a chemical pretreatment can occur (Jarvis & Schnürer, 2009). The nutritional and energy content is an important aspect (3.4) and biomass with a large surface area is considered to be beneficial in the digestion process because it makes it easier for the microorganisms to handle (Palmowski & Müller, 2000). In a study by Mshandete et al. (2006) where they investigated the degradation and biogas production potential of sisal fibre waste, it was concluded that grasses divided into smaller fractions increased the anaerobic degradation.

5.4 Alternative uses of the digestion residue

A residual product is formed by the material that did not break down during the digestion, which is called a digestion residue. It is rich in nutrients in terms of nitrogen, phosphorus and potassium and can therefore be used as fertilizer in agriculture (Berglund, 2006). 96% of all residues from the Swedish biogas production plants are currently used as biofertilizers on farmlands (Swedish Energy Agency, 2017).

Table 7; Compilation of the overall answer of the respondents. The questions asked in the interviews is to be find in Appendix 4, and these questions are then sorted under the sub-questions regarding the third question in this study "What can the the digestion residue from the biogas production of park waste be used as?"

Sub-questions	**Responded by**	**Summarized answer**
Can the digest residue from the biogas production be used for biochar production?	Respondent group 4 characterized by 4 respondents knowledgeable in biochar & biofertilizer (table 1)	Respondents are skeptical to if it is profitable to produce biochar of the digestion residue. And they say in that case, only the woody fractions from the park waste could be used in biochar production.
Does park waste fit better as a substrate for biochar production, or biogas production?	Respondent group 4 characterized by 4 respondents knowledgeable in biochar & biofertilizer (table 1)	As all material from the park waste can be used in biogas production, it is better suited than for bio-coal production, the respondents mean. The digest residue that comes from biogas production of park waste is also considered clean, which is sought after by farmers.

5.4.1 Used in the production of biochar

It is difficult to summarize an overall response from the respondents if it is worth making biochar from the digestion residue from park waste or not (table 7). But the residue from park waste is, in any case, a relatively pure digestate compared to, for example, litter from sewage sludge that may contain heavy metals, the respondents say.

Biochar is produced by pyrolysis of biomass under oxygen-free conditions, the biomass used must be classified as waste in order to be used in production (Mukherjee & Lal., 2013). A high lignin content biomass provides a better biochar than biomass with low levels of lignin (Wang et al., 2015). Wood-based biochar has been found to have higher carbon content than biochar produced of grass, this is due to the high lignin content and low content of combustible components in wood-based material (Wang et al., 2015)

Whit the right properties, the residues from biogas production can act as a feedstock within the biochar production (Stefaniuk & Oleszczuk, 2015), the properties of the biochar depends on the properties of the feedstock producing the biochar (Ibid). The respondents mean that a lot of energy will be needed when drying the digestion residue before it achieves the optimal feedstock characteristics, due to the large amounts of water in the digestion residue (3.2.1). This means that the digestion residue must be dried before it can be used to produce biochar. Also, since the components of the digestate are already relatively degraded (3.2), it is also not considered to give any major yield in a biochar production (Ibid).

The most favorable condition regarding biochar production from biogas production residues, is when the solid fraction is separated from the liquid fraction in the residues and produced under mesophilic conditions (3.3.5) (Stefaniuka et al., 2016; İnce et al., 2017). This contribute to a less toxic feedstock and a biochar containing less toxic contaminations and less toxic to living organisms (Stefaniuka et al., 2016). Biochars produced from residues from biogas production, contained low levels of heavy metals and PAH (Ibid).

The digestion residue can be used as biofertilizer and thus replace mineral and liquid fertilizers in agriculture, as the nutrients in the digestate residue are easily accessible to plants to absorb (Carlsson & Uldal, 2009). The digestion residue consists of organic materials, water, microorganisms and nutrients (Jarvis, 2012). It is considered beneficial to fertilize with biofertilizer as it helps to re-circulate nutrients to agriculture and nature (Swedish Energy Agency, 2010). The respondents also suggest that the digestion residue itself will make more use as a biofertilizer and a production of biochar will therefore not be favorable (table 7). Also, the respondents believed that the digestion residue of park waste will be a relatively pure material that that farmers will gladly receive.

Depending on the nature of the digestion residue, it may contain impurities and is therefore not suitable for fertilization. It has a decisive role in whether it can then be returned to agriculture as biofertilizer (Swedish Energy Agency, 2010). Unlike what the respondents thought, one problem with park waste is that it has been found to contain high levels of lead, cadmium, chromium and nickel in the study by Paulsson et al (2015), the park waste was obtained from a compost in Malmö which, like Helsingborg, is located in Skåne and can be considered to have similar conditions. The study assumes that the levels of heavy metals that exist before digestion also remain in the substrate after the digestion (Paulsson et al., 2015). The levels of the contaminants in the substrate put an end to the use of the digestion residue as a fertilizer, mainly because the cadmium content is too high (Paulsson et al., 2015).

There are criteria and limit-values that must be followed in order for the residue to be used as a biofertilizer, this applies to the content of heavy metals, disease-producing microorganisms and other visible pollutants (Jarvis, 2012).

With the help of the Swedish certification rules SPCR 120, the quality of the biofertilizer can be ensured, since it places demands on the entire biogas process, from incoming substrate to finished product (SP Swedish Technical Research Institute, 2010). The content of visible impurities in the biofertilizer must not exceed 0.5% by weight of the material's TS (SP Swedish Technical Research Institute, 2010). In other words, visible contaminants are undesirable materials such as plastic that is larger than 2 mm (SP Swedish Technical Research Institute, 2010).

5.4.2 Biochar or biogas production

As stated in table 7, some fractions of the park waste are suited for the biochar production. Furthermore, the respondents also stated that the materials that are primarily used in biochar production are cellulose-rich materials such as garden rice, branches / twigs from gardens, i.e. dry woody materials (table 7). The leaves / grass are sorted but may occur in small fractions during the production without it making any difference, they also mentioned that the material should be relatively dry and have a high cellulose content in order to be pyrolyzed. This suggests that only a certain part of the park waste can be used for bio-coal production, the woody fraction. Furthermore, the respondents also mentioned that just as for the digestion residue, the green and juicy part of the park waste contains a lot of water. It therefore have to be dried before it can be used in the production of biochar, which will make the process economically unsustainable as it will require a lot of energy they say.

In a study conducted by Paulsson et al. (2015), heavy metals in park waste were investigated. It was found that the content of nutrients in the park waste was low, which means that the content of heavy metals is relatively high in comparison. Since the levels of cadmium and lead turned out to be high in the tested park waste, it may be difficult to use the residue to remain after the digestion as biofertilizer on arable land.

The digestion residue consists mostly of water, which means that the content of the nutrients nitrogen and phosphorus in relation to the water content becomes very low (Dahlberg, 2011). From an economic perspective, this means that the costs for transport and storage and distribution of the digestion residue usually exceed the value for the production (Ibid). A de-watering of the digestate could reduce costs and increase the value of nutrients in the digestion residue (Ibid). But then one must also bear in mind that the de-watering process itself and the handling of the leftover water entail a cost (Ibid).

5.5 SWOT

The SWOT (strengths, weakness, opportunities, threats) (table 8) summarizes the primary conclusions regarding park waste as a substrate and refers to the various chapters earlier in this report. The purpose is to provide a quick and easy overview of the case study and the following questions that were investigated.

Table 8; A SWOT table of biogas production with park waste as a substrate.

Strengths	**Weakness**
- Benefit from local resources (5.2.1 & 5.2). - Relatively clean digestion residues (5.2.3 & table 8). -Increase the local biogas production (5.2.1). -RED II directive regarding renewable energy (4.1). -The new climate policy framework in Sweden (4.2). -(Lag 2017:1201) reduce GHG emissions (4.2) -The waste hierarchy (4.2). -Energy and climate strategy for Skåne 2018 (4.3). -Region Skåne's environmental strategy program (4.3). -Regional Development Strategy (RUS) (4.3).	-Helsingborg only have a wet-digestion plant (5.2.1). -Park waste will have to be pre-treated (5.2.2). -Lack of knowledge about park waste as a potential substrate (5.2.1). -The flow of park waste can be considered to be uneven during the year (5.2.2). - Low gas yield (5.2.1 & 5.2.3). - The differences between the different fractions (5.2.2)
Opportunities	**Threats**
-Build a dry-digestion plant (3.4 & 5.3.2). -Open up for digestion of new substrates (5.2.4). -Pretreatment to optimize the parke waste (3.4.4). -Promotes a local circular economy (5.2.1 & 5.3.1). -Socio-economic benefit of biogas production in Skåne (3.6.2). - Complement already existing substrates by co-digestion (5.2.2)	-Obstacles in a possible collaboration with and between Peab and Green regarding the park waste management (3.5.1). - Expensive to process / not economically Sustainable (5.2.3). -The cheap Danish biogas (5.2.3). - Risk for litter (5.2.2)

5.6 Further investigations

Theoretically, it is possible to produce biogas from park waste. This study can give an indication on what to focus on in future practical projects regarding park waste as a substrate. There are few studies on actual biogas productions that use plant material as a substrate. Furthermore, the existing studies are usually carried out on other plant materials than those that can be found in urban parks and meadows. This entails some uncertainty about how the actual park waste collected in Helsingborg matches the results in these studies.

It would be of great importance to test-digest the various fractions in the park waste from Helsingborg in order to see the actual potential. The result opens new doors for further studies in the field and expands the perspective on new substrates that can contribute to strengthening biogas production locally.

6. Conclusions

- All substrates that can be used in biogas production should be used considering the high competition for biogas today. It is important to create social benefits based on their own resources within Helsingborg.
- Generally, a dry-digestion can be considered to be the technically best suited for park waste as a substrate. It can also be an idea to sort the park waste into green juicy fractions and dry woody because they work best in different kinds of digestion processes.
- It is important to review each product step when assessing whether it is economically sustainable or not when thinking of trying a new source of substrate. In general, as long as the physical properties such as energy content and gas potential is considered to be reasonably good, there is nothing that speaks against that park waste will be more common in the future.
- Depending on whether the park waste is to be used in a wet or dry-digestion, different kinds of fractions are suitable. In the current wet-digestion plant in Helsingborg, grass, flowers and leaves fits the best. It is possible to digest the woody part of the park waste, but it will require pretreatments in terms of chipping and adding water. If Helsingborg in the future decide to build a dry-digestion plant, then all the fractions in the park waste gets the opportunity to be digested, even trimming debris from trees and shrubs.
- It is possible to produce biochar of the digestion residue, but since the digestion residue contains large amounts of water, it will have to be dried before its physical properties fit for the pyrolysis. Since the components of the digestion residue are already relatively degraded, it is also considered not to yield any major returns within the biochar production.

- The woody factions can at present be considered to be better suited for biochar production since Helsingborg currently only has wet-digestion where the woody fraction of the park waste does not fit. A biochar production prefer to use the woody factions to ensure an efficient production. Therefore, a collaboration between biogas and biochar producers would be beneficial. Were biochar producers use the woody fractions of the park waste and biogas producers the green moist fraction of the park waste.
- Stronger policy initiatives are needed to enable the biogas to develop and strengthen the Swedish biogas market.
- The results of this study are overall positive. However, practical investigations are needed to strengthen the relevance of the results.

7. Acknowledgements

I would like to start by expressing my gratitude to my supervisor Torleif Bramryd for your dedication to your role as my supervisor and for all the interesting discussions during this semester. Furthermore, I would like to say thank you to my vicarious supervisor Michael Johansson who supported me and Torleif when we needed it the most. Thank you to Widar Narvelo at Helsingborgs city development department and Madeleine Brask at Miljöbron for giving me the confidence to write this project in collaboration with you two. Thank you all for all your guidance and knowledge during this process.

Last, I would like to thank all the respondents who took their time to participate in this study, as well as PEAB, Green and Elisabeth Lindkvist from Helsingborgs city development department. Nor should I forget to thank my mom Mona Gustafsson for your last minutes inputs.

8. References

Books, theses and reports

Anderson S. Westling, N. Hising, J. Yelistratova, A. (2018). Värdet av den skånska biogasen - en samhällsekonomiska analys av biogasens nyttor. 2050 Consulting. Skåne.

Bate Holmberg, K. (2018). En skogsträdgårds näringspotential. Institutionen för biologisk grundutbildning, Uppsala universitet.17 pp.

Berglund, M. (2006). Biogas production from a systems analytical perspective. Environmental and Energy Systems Studies, Lund university. 50 pp.

Berglund, M., & Börjesson, P. (2003). Energianalys av biogassystem. (IMES/EESS Report No. 44). Department of Environmental and Energy Systems Studies, Lund university.

Bohn, I., Carlsson, M., Eriksson, Y. & Holmström D. (2010). Utvärdering och optimering av metod för förbehandling av källsorterat hushållsavfall till biogasproduktion. Rapport SGC 216. Svenskt Gastekniskt Center AB.

Björkmalm, J. (2013). Kartläggning av tekniska och processrelaterade problem och dess utvecklingsmöjligheter vid biogasanläggningar. Linköpings universitet, Institution för tema. Linköpings universitet. 68 pp.

Björnsson, L.; Prade, T.; Lantz, M. (2016). Grass for Biogas-Arable Land as Carbon Sink. An Environmental and Economic Assessment of Carbon Sequestration in Arable Land through Introduction of Grass for Biogas Production; Energiforsk: Stockholm/Malmö, Sweden. 125 pp.

Carlsson, M. & Uldal, M. (2009). Substrathandbok för biogasproduktion. Rapport SGC 200. Svenskt Gastekniskt Center AB. 34 pp.

County Administrative Board Skåne, (2011). Biogaspotential i Skåne – inventering och planeringsunderlag på översiktsnivå. Naturvårdsverket. Report 2011: 22 . Biogas Syd & Länsstyrelsen Skåne län.

Dahlberg, C. (2011). Biogödselförädling – Tekniker och leverantörer. SWECO Environment AB. Rapport 2011:03. Svenskt Gastekniskt Center. 47 pp.

Denscombe, M. (2014). The Good Research Guide : For Small-scale Research Projects. 5. uppl., Maidenhead, Berkshire: McGraw-Hill Education. 367 pp.

Deublein, D. and Steinhauser, A., Biogas from waste and renewable resources : Formation of biogas. 2008, Wiley-VCH. 578 pp.

Edström, M och Nordberg, Å (2004). Producera biogas på gården - gödsel, avfall och energigrödor blir värme och el. JTI. Rapport 107. 12 pp.

Energigas Sverige. (2018). Nationell biogasstrategi 2.0. Energigas Sverige. 7 pp.

European Environment Agency (EEA). (2017). Key Trends and Drivers in Greenhouse Gas Emissions in the EU in 2015 and Over the Past 25 Years. European Environment Agency. 7 pp.

Garcia Perez, A. (2014). Techno-economic feasibility study of a small-scale biogas plant for treating market waste in the city of El Alto. KTH Royal Institute of Technology. 47 pp.

Jarvis, Å. (2012). Biogas ur gödsel, avfall och restprodukter – Goda svenska exempel. Rapport 6518. Naturvårdsverket. Energigas Sverige. 111 pp.

Jarvis, Å och Schnürer, A. (2009). Microbiological Handbook for Biogas Plants
Swedish Waste Management. Report 207. Swedish Gas Centre. 134 pp.

Johannesson, P. Perjons, E. (2012). A Design Science Primer. Printed by CreateSpace. 143 pp.

Klimatsamverkan Skåne. (2018). Ett klimatneutralt och fossilfritt Skåne - klimat och energistrategi för Skåne. 81 pp.

Kommunförbundet Skåne. (2018). Climate and energy strategy for Skåne.

Mshandete, A., Björnsson, L. , Kivaisi, A-K., Rubindamayugi, M.S.T., Mattiasson, B. (2006). Biofuels for Fuel Cells. Renewable Energy. 31:2385–2392

Naturvårdsverket, (2012). Biogas ur gödsel, avfall och restprodukter - goda svenska exempel. Report 6518. 111 pp.

Nordberg, Ulf. (2006). Biogas - Nuläge och framtida potential. JTI – Institutet för jordbruks- och miljöteknik. Report T5-503. Värmeforsk. 89 pp.

Nordberg, U., och Nordberg, Å. (2007). Torrötning - kunskapssammanställning och bedömning av utvecklingsbehov. JTI – Institutet för jordbruks- och miljöteknik. Report 357. Stiftelsen Lantbruksforsknings FUD-program och Energimyndigheten. 59 pp.

Nordell, E. och Rönnberg, J. (2015). Torrötning av avvattnat rötslam vid termofil temperatur. Rapport 2015-05. Svenskt Vatten Utveckling. Svenskt vatten AB. 52 pp.

Lantz, M., Prade, T., Ahlgren, S., Björnsson, L. (2018). Biogas and Ethanol from Wheat Grain or Straw: Is There a Trade-Off between Climate Impact, Avoidance of iLUC and Production Cost?. Lund University and SLU Uppsala. 31 pp.

Odlare, M. (2007). Biogödsel och kompost - en resurs för jordbruket, resultat från ett fältförsök. Institutionen för samhällsteknik. Mälardalens högskola. 48 pp.

Paulsson, M., Svensson, S-E., Mattsson, J E. Mattiasson, B. (2015). Park- och trädgårdsavfall - en resurs för fastbränsle och biogas. Fakulteten för landskapsarkitektur, trädgårds- och växtproduktionsvetenskap. Report 2015:10. SLU Alnarp. 41 pp.

Region Skåne. (2017). Miljöstrategiskt program 2017-2020. Region Skåne. 22 pp.

Region Skåne. (2015). Skånes färdplan för biogas. Region Skåne. 8 pp.

Region Skåne. (2014). Det öppn skåne - Skånes regionala utvecklingsstrategi. Region Skåne. 48 pp.

SP Sveriges Tekniska Forskningsinstitut. (2010). Certifieringsregler för biogödsel - SPCR 120. SP Sveriges Tekniska Forskningsinstitut, Borås. 23 pp.

Stjärna. H. (2014). Biogaspotential i park- och trädgårdsavfall. Miljö- och Energisystem
Institutionen för Teknik och samhälle. Lunds tekniska högskola. 85 pp.

Swedish Energy Agency (2010). Förslag till en sektorsövergripande biogasstrategi. Report 2010:23. Statens energimyndighet. 185 pp. Statens energimyndighet & Energigas Sverige.

Swedish Energy Agency. (2018). Produktion och användning av biogas år 2017. Statens energimyndighet rapport: Report 2018:01. Stockholm. Statens energimyndighet & Energigas Sverige. 24 pp.

Trafikverket. (2016). Åtgärder för att Minska Transportsektorns Utsläpp av Växthusgaser—Ett Regeringsuppdrag. Trafikverket. Report 2016:111. Trafikverket: Boren, Sweden. 79 pp.

Wannholt, L. (1998). Biologisk behandling av hushållsavfall i slutna anläggningar i Europa – huvudrapport. Report 98:7. Malmö: Daleke Grafiska AB. 110 pp.

Skåne County Administrative Board. (2018). A climate-neutral and fossil-fuel-free Skåne. Report 2018:17. Climate and energy strategy for Skåne County Administrative Board in Skåne county

Swedish Energy Agency. (2017) Produktion och Användning av Biogas och Rötrester år 2016; ES 2017:07; Swedish Energy Agency: Eskilstuna, Sweden, 201

Laws and regulations

Avfallsdirektivet beslutades inom EU 2008 och ersatte tre gamla direktiv: ramdirektivet (2006/12/EG) om avfall, direktiv (91/689/EEG) om farligt avfall och direktiv (75/439) om spillolja.

EU directive (2009/28/EC) On the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. The European parliament and council.

EU directive (2009/28/EC) of the european parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Off. J. Eur. Union 2009, L140, 16–62.

EU directive (2015/1513) amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources. The European parliament and council.

European Commission (EC). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions—A Policy Framework for Climate and Energy in the Period from 2020 to 2030; COM (2014) 15 Final; European Commission: Brussels, Belgium, 2014.

EU directive (2015/1513 of the European Parliament and of the Council of 9 September 2015 Amending Directive 98/70/EC Relating to the Quality of Petrol and Diesel Fuels and Amending Directive 2009/28/EC on the Promotion of the Use of Energy from Renewable Sources; European Union: Brussels, Belgium, 2015.

Helsingborg city. (2018). Climate and energy plan for Helsingborg 2018-2024. DNR: 100-17 SID 2 (16).

RED II. (2019). Renewable Energy – Recast to 2030. European parliament.

Region Skåne. (2015). Skånes färdplan för biogas. Region Skåne.

SFS nr: 2017:1201. (Lag 2017:1201) om reduktion av växthusgasutsläpp genom inblandning av biodrivmedel i bensin och dieselbränslen. Stockholm:

Justitiedepartementet.

Personal communication

Bramryd, Torleif. Professor of Environmental Strategy, researcher within biogas at Lund University campus helsingborg. Oral and email communication.

PEAB construction. Responsible manager. Email communication.

Lindkvist, Elisabeth. Development Engineer at the development department in Helsingborg city. Email communication.

Narvelo, Widar. City ecologist at the development department in Helsingborg city. Email communication.

Green landscaping. Responsible manager. Email communication.

Research articles

Chiumenti, F. d. Borso och S. Lumina. (2017). Dry anaerobic digestion of cow manure and agricultural products in a full-scale plant: efficiency and comparison with wet fermentation. Waste Management. 71:704-710.

Hansen, T. L., la Cour Jansen, J., Davidsson, Å. & Højlund Christensen, T. (2007). Effects of pretreatment technologies on quantity and quality of source-sorted municipal organic waste for biogas recovery. Waste Management. 27:398 - 405.

Grzeszczuk, M., Stefaniak, A. & Pachlowska A. (2016). Biological values of various edible flower species. ACTA Scientiarum Polonorum Hortorum Cultus. 15:109–119.

Igoni, A.H. Ayotamuno, M.J. Eze, C.L. Ogaji, S.O.T. Probert, S.D. (2008).

Designs of anaerobic digesters for producing biogas from municipal solid-waste. Applied Energy. 85:430- 438.

Lehmann, J. & Stephen, J. (2009). Biochar for environmental management- an introduction. In: Lehmann, J. & Joseph, S. (Eds.). Biochar For Environmental Management: Science And Technology. Earthscan, London. 1:448.

Lissens, G., Vandevivere, P., Baere, D., Biey, E. M., & Verstraete, M. (2001). Solid waste digestors: process performance and practice for municipal solid waste digestion. Water Science and technology. 44:91-102.

Mukherjee, A., & Lal, R. (2013). Biochar Impacts on Soil Physical Properties and Greenhouse Gas Emissions. Agronomy. 3: 313-339.

Palmowski L, Müller J. (2000). Influence of size reduction of organic waste on their anaerobic digestion. Water Sci Technol. 41:155–62.

Parawira, W., Murto, M., Read, J.S. and Mattiasson, B. (2005). Profile of hydrolases and biogas production during two-stage mesophilic anaerobic digestion of solid potato waste Process Biochemistry. 40:2945-2952.

Parawira, W., Read, J.S., Mattiasson, B., Björsson, L. (2008). Energy production from agricultural residues: High methane yields in pilot-scale two-stage anaerobic digestion. 32: 44-50.

Salehiana, P., Karimiab, K., Ziloueia, H., Jeihanipourc, A. (2013). Improvement of biogas production from pine wood by alkali pretreatment. 106: 484–489.

Schink, B. (1997). Energetics of syntrophic cooperation in methanogenic degradation. Microbiology and Molecular Biology Reviews. 61: 262-280.

Stefaniuk M., Oleszczuk P. (2015). Characterization of biochars produced from residues from biogas production. Journal of analytical and applied pyrolysis. 115: 157-165.

Stefaniuka M., Oleszczuka P., Bartmińskib P. (2016). Chemical and ecotoxicological evaluation of biochar produced from residues of biogas production. Journal of hazardous materials. 15: :417-424.

Wang, J. Xiong, Z. Kuzyakov, Y. (2015). Biochar stability in soil: meta-analysis of decomposition and priming effects. 8: 512-523.

Weiland, P. (2010). Biogas production: current state and perspectives. Applied Microbiology and Biotechnology. 85: 849–860.

Wikandari, R., Gudipudi, S., Pandiyan, I., Millati, R., Taherzadeh, MJ. (2013) Inhibitory effects of fruit flavors on methane production during anaerobic digestion. Bioresource Technology. 145:188-92.

Zhu, C., Zhang, J., Tang, Y., Zhengkai, X. and Song, R. (2011). Diversity of methanogenic archaea in a biogas reactor fed with swine feces as the mono-substrate by mcrA analysis. Microbiological Research. 166: 27-35.

Web sites

Biogas2020. (2017). Kart over fyllestasjoner:
https://www.biogas2020.se/kart-over-fyllestasjoner-for-biogass/
[Accessed February 15, 2019]

County Administrative Board Skåne. (2019a). Miljötillståndet Skåne - sammanfattning 2019:
http://skanesmiljomal.info/sammanfattning-2019/
[Accessed January 27, 2019]

County Administrative Board Skåne, (2019b). Begränsad klimatpåverkan:
http://skanesmiljomal.info/project/begransad-klimatpaverkan-2019/
[Accessed January 75, 2019]

Government Offices of Sweden. (2018). Bättre stöd till svensk biogas. https://www.regeringen.se/pressmeddelanden/2018/04/battre-stod-till-svensk-biogas/
[Accessed March 6, 2019]

Leijonhufvud, P. (2014). *Användbara växter i skog och mark*. Svenska Överlevnadssällskapet Tredje upplagan. https://docplayer.se/5602972-Anvandbara-vaxter-i-skog-och-mark.html
[Accessed February 29, 2019]

Moberg's processkontroll AB. (2011). Återvinning. Hämtat från:
http://metalldetektorer.se/produkter/atervinningsindustrin/
[Accessed March 24, 2019]

Swedish Energy Agency. (2017). Fler substrat kan bli biogas med nya rötningstekniker.
http://www.energimyndigheten.se/effekter-av-vara-satsningar/fler-substrat-kan-bli-biogas-med-nya-rotningstekniker/
[Accessed January 22, 2019]

The Government of Sweden. (2017). En klimatstrategi för Sverige. https://www.regeringen.se/rattsliga-dokument/skrivelse/2018/04/skr.-201718238/

[Accessed Febryary 26, 2019]

Weibulls, grässorter. (2019):
https://weibulls.com/tradgarden/grasmatta/grassorter/1026307.1393050.1394722a
[Accessed March 24, 2019]

Appendix 1 - Interviews regarding the basic questions

The following 7 questions were asked to all respondents (traffic / logistics respondents were excluded). All the interviews were performed in Swedish, hence the Swedish questions below.

1. Har du tidigare hört talas om parkavfall som substrat till biogasproduktion?
   - Om ja: hur/vad?

(Have you previously heard about park waste as a substrate for biogas production?
If yes: how / what?)

2. Vad kan anses säga emot användningen av parkavfall som substrat för biogasproduktion?

(What can speak against the use of park waste as a substrate for biogas production?)

3. Vad kan anses tala för en användning av parkavfall som substrat för biogasproduktion?

(What can be considered to speak in favour regarding the use of park waste as a substrate for biogas production?)

4. Tror du att parkavfall kommer behöva mer komplex processering än de substrat som vanligtvis används?

(Do you think park waste will need more complex processing than the commonly used substrates?)

5. Finns det en möjlighet att blanda in parkavfall i nuvarande “vanliga” substrat till biogasproduktion?

(Is it possible to mix in park waste in the current "common" substrate for biogas production?)

6. Kommer det behövas fler steg under produktionen av biogas med parkavfall som substrat?

(Will more steps be needed during the production of biogas with park waste as a substrate?)

7. Tror du att parkavfall som substrat kommer bidra till någon skillnad i kostnader? T.ex. genom extra steg? Färre steg? Mer men billigare steg? Färre men dyrare steg? Transporter? Osv.

(Do you think park waste as a substrate will contribute to any difference in costs? E.g. through extra steps? Fewer steps? More but cheaper steps? Fewer but more expensive steps? Transportation? Etc.)

Appendix 2 - Interviews regarding biogas production

The following 6 questions were asked to respondent group 3 (Table 1, Chapter 2) who were considered to be knowledgeable regarding the aspects of the production of biogas. All the interviews were performed in Swedish, hence the Swedish questions below.

1. Vad är de viktigaste aspekterna när det kommer till substratets egenskaper?
   (What are the most important aspects when it comes to the properties of the substrate?)

2. Kan man anse det vara tekniskt genomförbart eller ej att producera biogas av parkavfall?
   (Can one consider it technically feasible or not to produce biogas from park waste?)

3. Vilka växter skulle du anse passade bäst till biogasproduktion?
   (Which plants would you consider best suited to biogas production?)

4. Hur har användningen av substrat generellt förändrats över tid gällande biogasproduktion? Och hur tror du att det kommer att se ut i framtiden?
   (How has the use of substrates generally changed over time regarding biogas production? And how do you think it will look in the future?)

5. Vart kommer de vanligaste substraten ifrån och hur samlas det in?
   (Where do the most common substrates come from and how are they collected?)

6. Kan du se en framtida marknad för parkavfall som substrat?
   (Can you see a future market for park waste as a substrate?)

7. Vill du tillägga något som du inte anser att vi tagit upp?
   (Do you want to add something that you do not think we raised?)

Appendix 3 - Interviews regarding goals and regulations

The following 8 questions were asked to respondent group 2 (Table 1, Chapter 2) who were considered to be knowledgeable within Skåne and Helsingborg's goals and regulations. All the interviews were performed in Swedish, hence the Swedish questions below.

1. Kan du berätta om de viktigaste målen inom energi-/klimatsektorn i Skåne just nu?
   (Can you tell us about the most important goals in the energy / climate sector in Skåne right now?)

2. Hur tror du att substrat till biogasproduktion kommer att förändras i framtiden?
   (How do you think that substrate for biogas production will change in the future?)

3. Tror du att konceptet parkavfall som substrat inom biogasproduktionen kommer att bli mer/mindre vanligt i framtiden?
   (Do you think the concept of park waste as a substrate in biogas production will become more / less common in the future?)

4. Finns det några incitament för att användandet av parkavfall som substrat till biogasproduktionen kommer öka?
   (Are there any incentives for increasing the use of park waste as a substrate for biogas production?)

5. Vad har du för åsikter gällande parkavfall som substrat till biogasproduktionen?
   (What do you think of park waste as a substrate for biogas production?)

6. Kan du se en framtida marknad för parkavfall som substrat?
   (Can you see a future market for park waste as a substrate?)

7. Kommer värdet av parkavfallet att öka eller minska när det används som substrat inom biogasproduktion jämfört med om det komposteras/förbränning?
   (Will the value of park waste increase or decrease when used as a substrate in biogas production compared to if it is composted / incinerated?)

8. Vill du tillägga något som du inte anser att vi tagit upp?
   (Do you want to add something that you do not think we raised?)

Appendix 4 - Interviews regarding biochar and biofertilizer

The following 7 questions were asked to respondent group 4 (Table 1, Chapter 2) who were considered to be knowledgeable regarding biochar, biofertilizer and the digestion residues of biogas production. All the interviews were performed in Swedish, hence the Swedish questions below.

1. Vart kommer det råmaterial ni använder för tillfället ifrån?
(Where does the raw material you currently use come from?)

2. Kan du nämna de viktigaste egenskaperna hos ett råmaterial för biokolsproduktion?
(Can you mention the main characteristics of a raw material for biocarbon production?)

3. Jämfört med andra råmaterial för produktion av biokol, hur tror du att rötresten från parkavfall kommer att te sig?
(Compared to other raw materials for the production of biochar, how do you think the rust residue from park waste will occur?)

4. Finns det ett värde i att producera biokol av rötrester från biogasproduktion?
(Is there a value in producing biochar from digestate from biogas production?)

5. Om rötresten kommer från en biogasproduktion baserat på parkavfall, hur skulle värdet se ut då?
(If the digestate comes from a biogas production based on park waste, how would the value look then?)

6. Kan du se en framtid i biokolsproduktion av rötrest från parkavfall?
(Can you see a future in biochar production of litter waste from park waste?)

7. Vill du tillägga något som du inte anser att vi tagit upp?
(Do you want to add something that you do not think we raised?)

Appendix 5 - Interviews regarding biochar and biofertilizer

The following 7 questions were asked to respondent group 5 (Table 1, Chapter 2) who were considered knowledgeable in transporting of substrates within biogas production and the logistics around it. All the interviews were performed in Swedish, hence the Swedish questions below.

1. Hur ser du på potentialen av att använda parkavfall som substrat till biogasproduktion, relaterat till transporten?
   (How do you see the potential of using park waste as a substrate for biogas production, related to transport?)

2. Skulle det vara möjligt att transportera parkavfallet direkt från nuvarande uppsamlingsplatser för parkavfall? Eller kommer logistiken runt det att behöva anpassas?
   (Would it be possible to transport the park waste directly from the current collection sites for park waste? Or will the logistics around it have to be adapted?)

3. Tror du det kommer innebära längre/fler transporter vid användning av parkavfall som substrat jämfört med de mer originella substraten till biogasproduktion?
   (Do you think this will mean longer / more transports when using park waste as a substrate compared to the more original substrates for biogas production?)

4. Logistiskt sett, är det genomförbart att använda parkavfall som substrat till biogasproduktion?
   (Logistically, is it possible to use park waste as a substrate for biogas production?)

5. Hur skulle parkavfallet behöva transporteras mellan platsen för uppkomsten av avfallet och produktionen av biogasen? Skiljer det sig utifrån de originella substraten, blir det dyrare/billigare?

(How would the park waste be transported between the site for the origin of the waste and the production of the biogas? Does it differ from the original substrates, does it become more expensive/cheaper?)

6. Kommer det innebära några förändringar i kostnaderna om man jämför parkavfall och "vanliga" substrat?
   (Will there be any changes in the costs if you compare park waste and "regular" substrates?)

7. Skulle du anse det här vara genomförbart?
   (Would you consider this to be feasible?)

LUNDS UNIVERSITET

WWW.CEC.LU.SE
WWW.LU.SE

Lunds universitet

Miljövetenskaplig utbildning
Centrum för miljö- och klimatforskning
Ekologihuset
223 62 Lund