DEPARTMENT OF TECHNOLOGY AND BUILT ENVIRONMENT

ASSESSMENT OF WASTE AND BIOFUEL RESOURCES FOR DISTRICT HEATING IN THE REGION OF GÄVLE IN SWEDEN

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Master’s Thesis in Energy Systems
Preface

This study was carried out as a final thesis at the Master in Energy Systems programme in the University of Gävle, in collaboration with the company Gävle Energi.

First of all, I would like to thank my supervisor at Gävle Energi, Åke Björnwall, whose attention, comments and advice have been of great help for the development of my work.

Secondly, I would like to thank Shahnaz Amiri at the University of Gävle for her help during the time of the realization of the work.

I would also like to thank Per-Olof Hallberg from Gästrike Återvinnare and Peter Hallner from Sita Sverige, for accepting my visit to the companies, for their explanations regarding their activities, and the valuable answers obtained for my work.

Finally, I would like to thank all the people working in other companies from which I received an answer by mail; no one mentioned, no one forgotten.

June 2008.

Laura Alonso Ojanguren.
Abstract

Sweden is one of the leading biofuel users in the European Union. The national energy policy encourages the use of biomass since the early 1970s. Thanks to the carbon dioxide tax and the sulphur tax, which are levied on fossil fuels, biomass is the most competitive fuel for district heating. The district heating sector is one of the largest users of biofuels. There is great potential for the use of by-products arising from pulp production facilities, as well as from other wood related industries. Waste, on the other hand, has been used for district heating production in Sweden since the 1970s. It is also an important source of energy, which can be used for energy purposes. Finally, peat is an extensive resource in Sweden, and its utilization for district heating is a better option than the usage of fossil fuels.

Fuel availability and security of supply are two of the most important factors in the well functioning of a company like Gävle Energi. Another important factor is the price of the fuels used. The transportation cost plays also an important role when purchasing fuels from different sources. Currently the fuels used in Gävle Energi are mainly woody biofuels, but waste and peat could also be used in the future.

The aim of this thesis is to provide an overview of the different available biofuels in the region of Gävle. The fuels considered in the study are:
- Bark
- Forest Residues
- Wood waste
- Pellets and Briquettes
- Garbage/waste materials
- Peat

The research is focused on the physical properties of the fuels, their price and transportation cost, environmental and legislation issues and the availability in the region of Gävle. A 10-year perspective is defined for an estimated availability of the different fuels in the region.

For the realization of the work, the study of literature concerning biofuels, peat and waste is one first important step. With internet sources and other thesis’ information the fuels of
study are defined. Physical properties, price, environmental issues and legislation are covered.

A brief description of the power and heat production in Gävle is included in the work.

The calculation of an average cost of transportation for the fuels is another important step of the work, in which different sources from companies have been used. With the transportation cost defined, a reasonable distance of transport is defined around the municipality of Gävle. Within this distance the most important actors of wood processing industries are researched, in order to get information regarding the availability of woody biofuels in the region. For the availability of waste, the biggest municipalities around Gävle are researched, in order to find out the amount of waste produced and nowadays’ place of incineration of the combustible waste. In order to get the information, questionnaires are sent to the companies, and personal interviews are carried out in some of them.

From the point of view of the physical properties of the fuels, the best fuels for combustion are pellets and briquettes, and they will also have the lowest transportation cost. Bark and forest residues have the lowest calorific value as received. Wood waste, peat and waste materials have intermediate values.

From the point of view of price, waste is the cheapest source of energy, followed by unrefined woody biofuels and peat. Refined woody biofuels, on the other hand, are the most expensive fuels, and even if their heating value is the highest, the price that has to be paid for energy unit does not compensate this. The transportation cost is the highest for woody biofuels. Nevertheless, the calculated value should not be considered as exact. Moreover, it should be born in mind that the transportation cost might change depending on the distance of transportation.

The prices of the considered fuels tend to remain more constant when compared to other fossil fuels, like petrol or natural gas. The fuels which are becoming more expensive are refined woody biofuels.

From the point of view of the environment, the fuel that leads to higher emissions of CO\(_2\) to the atmosphere is peat, followed by waste. Finally, woody biofuels are considered CO\(_2\) neutral. On the other hand, other emissions to the atmosphere have significantly decreased over the last years, due to the improvements in technology of depuration.
From the point of view of legislation, woody biofuels are the most benefited from EU legislation and national policies and measures. They are benefited from the electricity certificate system, and the fact that they are CO₂ tax, NO₂ tax and sulphur tax exempt also makes their use more profitable in the present.

The use of peat is also benefited when compared to fossil fuels. It is included in the electricity certificate system, and is CO₂ tax exempt. However, it is not exempt from NO₂ tax and sulphur tax, therefore, it has less advantages than woody biofuels in this sense.

Finally, waste has less advantage, because an incineration tax is levied on the waste. However, its use for combustion is more profitable than the use of fossil fuels.

From the point of view of availability of woody biofuels in the region of Gävle, in the future the most important sources of woody biofuels will continue to be the big pulp mills around Gävle. It is difficult to predict changes in prices and availability, because there are too many actors in the market, and the companies which sell their by-products do not reveal the prices, due to competition reasons.

From the point of view of availability of waste in the region of Gävle, the municipalities that could provide a waste incineration plant in Gävle are those in which the waste is nowadays collected by Gästrike Återvinnare and Sita Sverige, is that, the combustible waste that is transported to Forsbacka waste dump, and after that, to Uppsala and Sundsvall. It would me more profitable to transport that amount of waste to an incinerator situated in Gävle. The availability of waste is not predicted to change significantly in the incoming years, due to the relative stability in population. It could be slightly increased, but current values could be used when making estimations of the yearly available quantity.
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1. Introduction

1.1. Background

1.1.1. Use of biofuels, peat and waste

Sweden is one of the leading biofuel users in the European Union. Forestry and the forest industry are key sectors for the biofuel market, as practically all the biomass used in Sweden originates from the forests. Forest land area in Sweden accounts for 27 million hectares, which corresponds to 60% of the land area in Sweden.

Following the forest industry, the second larger user of biofuels is the district heating sector. It supplies more than 40% of the heat in buildings. In this sector, biofuels include used wood, apart from the forest industry products.

In Sweden there is a great potential for the use of the by-products arising from pulp production facilities and other wood related industries. The middlemen between wood fuel producers and consumers are often the biofuel trading companies. These companies supply district heating plants, as well as industries and small-scale users with biofuels. For instance, in Fig. 1 an example of the wood fuel chain is depicted.

Fig. 1. Example of an integrated raw material and wood fuel procurement chain. [1]
The reason why biomass plays an important role in energy production in Sweden is the national energy policy, which encourages the use of biomass since the early 1970s. After the energy tax reform in 1991, the use of biomass in district heating facilities has rapidly expanded. The reform introduced a carbon dioxide tax and a sulphur tax on fossil fuels. Therefore biomass, being exempt from these taxes, became the most competitive fuel for district heating.

Each EU citizen produces an average of more than 500 kg of MSW (municipal solid waste) per year. It is an important amount of waste that can be used for energy purposes. Waste has been used for district heating production in Sweden since the 1970s. During the last decades strategies and policies have shifted the tendencies from landfill disposal to incineration. Nowadays, technology concerning waste incineration has been greatly improved, achieving a lower level of emissions, which allows using this alternative for waste-to-energy purposes.

Concerning peat, Sweden has a vast amount of resources, as it is covered by about 25% peat. Of this quantity only about 0.1% is being harvested in the present. The use of peat has a direct impact on peat lands, therefore, a sustainable method of harvesting and utilising the peat is necessary in order to achieve a sustainable method of producing heat and power from this fuel. The use of peat for district heating is a better alternative than the use of fossil fuels. Moreover, combustion of peat mixed with woody biofuels improves the combustion in the boiler. [2]

In Fig. 2 the role of biofuels and peat in the district heating sector in Sweden is shown. Nowadays, most of the district heating plants in Sweden work burning woody biofuels and peat, and an increasing number of waste incineration plants are in operation as well.

In Fig. 3 the use of different biofuels in the district heating sector in Sweden from 1980 to 2006 is shown. Woody biofuels are the most used fuels in the district heating sector.
Fig. 2. Energy input for district heating, 1970-2006 [3]

Fig. 3. Use of biofuels, peat, etc. in district heating plants, 1980-2006 [3]
1.1.2. Gävle Energi

Gävle Energi is a company which supplies electricity and heat for the municipality of Gävle. It has a wide district heating network in the majority of the municipality.

Currently the fuels used in the district heating plant owned by Gävle Energi are renewable fuels; mainly bark, forest residues and wood waste.

Fuel availability and security of supply are two of the most important factors in the well functioning of a company like Gävle Energi, as it is the responsible of the supply of heat and power to Gävle. Another important factor is the price of the fuels used in the combustion facility. As these fuels are mainly woody biofuels, the transportation cost is also a very important issue, because it defines the maximum profitable distance of transport for the purchased biofuels.

Waste and peat are other fuels that could be used for district heating in Gävle. The possibility of using the waste generated in Gävle and its surrounding municipalities for heating and power purposes is viable, as well as waste from nearby industries. Waste has the advantage of being a really cheap fuel for district heating plants; however, the construction of a waste incineration facility requires a high investment. Peat, on the other hand, is a fuel that has both advantages and disadvantages, as it is not considered “entirely” renewable.

1.2. Aim and scope

1.2.1. Aim and research questions

The aim of the thesis is to provide an overview of the different available biofuels in the region of Gävle for their use in the district heating sector. The fuels considered in the study are:

- Bark
- Forest Residues
- Wood waste
- Pellets and briquettes
- Garbage/waste materials
- Peat

The research is based on the availability of these biofuels in the region of Gävle. For the availability of woody biofuels, attention is drawn to big industries around Gävle that have by-products arising from their production processes. For the availability of waste, municipalities included within a reasonable distance from Gävle are researched, to define their yearly household waste quantities. Companies that treat industrial waste are also researched.

The research questions included in the thesis are the following:
- Physical properties and characteristics of the fuels
- Price of the fuels
- Environmental issues
- Legislation
- Transportation cost of the fuels
- Availability of the fuels in the region of Gävle

A 10-year perspective is defined for an estimated availability of the different fuels in the region. A comparison of the different fuels concerning the research questions mentioned before is also made.

1.2.2. Limitations

The main limitation for the work is the amount of information obtained from the different companies. The goal was to obtain as much information as possible from the companies. However, the majority of the questionnaires sent were not entirely answered, and the quality of the answers was not always good. The best sources of information were the companies where personal interviews were carried out: Gävle Energi, Gästrike Återvinnare and Sita Sverige. Of course another limitation was the duration of the thesis project. If more time was available for the realization of the thesis, it would have been possible to get more information from the companies.

The other limitation was the quality of the answers obtained from the companies. In many cases, different sources offered different results, and a definitive conclusion could not be
reached. However, some of the data offer interesting issues to think about when purchasing fuels for the district heating plant.

The issue of the prices of the different fuels is limited in this work. For the prices of woody biofuels and peat, average prices for different years are presented. However, fuel prices paid by individual plants, or for imported biofuels on the other hand, are difficult to obtain since the district heating companies act on a competitive market [4].

A good average for the price of waste is difficult to obtain, since the waste incineration tax is different in each case, depending of how much heat and electricity is produced. However, the tax system is not studied in a thorough way, but commented in the legislation section. The transportation cost is in much cases included in the overall price, therefore the price paid to incinerate the waste itself is difficult to know. Other factor that influences the price is the competition between different companies, which in many cases do not reveal their prices.

Another issue is the transportation cost. The calculated transportation costs for the different fuels may change depending on the distance of transportation, and should not be considered as exact values.

1.3. Outline of the thesis

In section 2 the biofuels of study are presented. Firstly, in section 2.1 each of the biofuels considered in the study is briefly described. In section 2.2 the physical properties and other characteristics of the fuels are shown, as well as some comparisons between their physical properties. Finally, in section 2.3 the changes in the price of fuels over the years are depicted.

In section 3 environmental issues are discussed. Firstly, in section 3.1 CO₂ emissions arising from the combustion of the different fuels are explained. In section 2.2 other emission to the atmosphere are described, and in section 2.3 the issue of ash handling is depicted.

In section 4 an overview of the current legislation is shown. In section 4.1 EU directives which have an impact on the use of the fuels of study are explained, as well as the implementation of those directives in Swedish legislation. In section 4.2 Sweden´s energy
policy is depicted, and the most important administrative and economic policy measures are explained. Finally, section 4.3 includes a summary of the impact that EU legislation and national policy measures have on the fuels of study.

In section 5 a description of the power and heat production in the municipality of Gävle is included, with focus in the district heating system. A more detailed description of the district heating plant of Johannes is available in Appendix 3.

In section 6 the method used in the thesis is depicted. In section 6.1 the planning of the research done is explained, and in section 6.2 an explanation of the different surveys and interviews necessary for the collection of data is included.

In section 7 the results originated from the data obtained by the research made are shown. Firstly, the transportation price is depicted in section 7.1. Secondly, in sections 7.2 and 7.3 the availability of biofuels and waste is shown.

In section 8 the attained results are discussed. The strengths and the weaknesses of the work are explained, and some important conclusions are drawn.

Finally, in section 9 the possibilities of further research are explored, and some suggestions for further work are made.
2. Biofuels, peat and waste

2.1. Definition of biofuels, peat and waste

A biofuel is a renewable fuel originated from organic sources, therefore it is biodegradable. EU legislation defines biomass as “...the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste...” (Directive 2001/77/EC).

2.1.1. Bark

Bark is the outer layer of stems and roots of woody plants, such as trees. It is a byproduct principally from pulp mills when the bark is peeled off from the logs. The amount of bark varies with the type of tree and its age, but approximately 10-15% of a tree log is bark.

2.1.2. Forest residues

Forest residues typically refer to those parts of trees unsuitable for sawlogs: treetops, branches, small-diameter wood, stumps, dead wood, and even misshapen whole trees – as well as undergrowth and low-value species. There is a special Swedish word that defines some of the forest residues, namely GROT. Its meaning is gren, rot och topp (branches, stumps and tops).

2.1.3. Wood waste

Wood waste usually arises in many industries and commercial companies, and it is rarely traded but used on site. The reporting enterprise may be able to state or estimate the quantity used or to state the heat obtained from it. Waste wood includes manufacturing and wood processing wastes, as well as construction and demolition debris.

CEN/TS 14588 defines used wood as “wood substances or objects which have performed their intended purpose”. Used wood should not include heavy metals or halogenated organic compounds. Demolition wood is defined as “used wood arising from demolition of buildings or civil engineering installation”. It is not classified as biomass and it should be handled under the Waste Incineration Directive.
2.1.4. Pellets and briquettes

Wood pellets and refined biomass fuel briquettes are usually cylindrical compressed wood fuel products made from the residues and byproducts of the mechanical wood processing industry. They are usually called processed wood fuel. The raw material is dry or moist sawdust, grinding dust and cutter shavings. Pellets and briquettes can also be compressed from fresh biomass, bark and forest chips, but the raw material must be milled and dried before pelletising. Herbaceous and fruit biomass can also be used as raw material.

Pelleted fuel is manufactured with the addition of lignin binders. It has low moisture content at the time of manufacture (~10%). The moisture content and heating values for chips and pellets are usually specified by the suppliers.

Pellets are short cylindrical or spherical pieces with a diameter less than 25 mm. Briquettes are rectangular or round pieces, bigger than pellets.

2.1.5. Garbage/waste materials

Waste is a fuel consisting of many materials coming from combustible industrial, institutional, hospital and household waste, such as rubber, plastics, waste fossil oils, and other similar commodities. It is either solid or liquid in form, renewable or non-renewable, biodegradable or non-biodegradable.

The following definitions can be found in the Energy Statistics Manual of the International Energy Agency (IEA) [5]:

- Industrial wastes: Wastes of industrial non-renewable origin (solids or liquids) combusted directly for the production of electricity and/or heat. The quantity of fuel used should be reported on a net calorific value basis. Renewable industrial waste should be reported in the Solid Biomass, Biogas and/or Liquid biofuels categories.

- Municipal solid waste (renewables): Waste produced by households, industry, hospitals, and the tertiary sector which contains biodegradable materials that are incinerated at specific installations. The quantity of fuel used should be reported on a net calorific value basis.
- Municipal solid waste (non-renewables): Waste produced by households, industry, hospitals, and the tertiary sector which contains non-biodegradable materials that are incinerated at specific installations. The quantity of fuel used should be reported on a net calorific value basis.

As it is also stated in the Energy Statistics Manual, some controversy is present in the definition of municipal solid waste. The reason is that in the waste there are both biodegradable and non-biodegradable components. That is why in the anterior definitions a distinction between renewable MSW and non-renewable MSW is made. Both IEA and European Union definitions of renewables exclude non-biodegradable municipal solid waste; however, some member countries count all MSW as renewable. In the 1990s, the Swedish Biofuel Commission found that approximately 85% of waste could be considered biofuel [6].

2.1.6. Peat

Peat consists in dead organic, plant-based matter, which has accumulated in waterlogged conditions. The deepest layers of peat are older, while the outer ones are the most recently formed layers. Peat is not always considered as a renewable fuel, since it takes thousands of years for its renovation. Peat is commonly blended with other renewable fuels, as it improves combustion properties of the fuel mixture.

2.2. Physical properties and characteristics of biofuels, peat and waste

The combustion properties of a fuel are determined by a series of chemical and physical characteristics. These characteristics also determine the suitability of a fuel for a certain type of boiler. The most important parameter of a fuel is its calorific value.

The calorific value of a fuel is most affected by moisture content and ash content. The higher the moisture content, the higher the amount of water in the fuel, which evaporates during the combustion process, binding energy in the vapour. As a result, the combustion temperature is lower, and the flue gas volume which has to go through the boiler is increased.
The ash is the rest product after the combustion, and it consists of non-combustible inorganic components. Variations of ash content in the fuel are mainly caused by treatment, storage conditions and production technique [7].

The following issues need to be borne in mind when utilising biofuels for combustion [8]:
- Storage of the fuel can increase the risk of degradation of the fuel and the apparition of mould.
- An adequate particle size is an important parameter for combustion.
- If different biofuels are being used, the correct mixing of the fuels is an important factor for a stable combustion process.

The physical properties of the biofuels of study are presented in Table 1.

Table 1. Physical properties of the biofuels of study

<table>
<thead>
<tr>
<th>FUEL</th>
<th>Net calorific value (dry content) (MWh/t)</th>
<th>Moisture (%)</th>
<th>Net calorific value as received (MWh/t)</th>
<th>Bulk density (kg/m³)</th>
<th>Energy density as received (MWh/m³ loose)</th>
<th>Ash content, dry (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bark, coniferous (1)</td>
<td>5.14-5.56</td>
<td>50-65</td>
<td>1.38-2.50</td>
<td>250-350</td>
<td>0.50-0.70</td>
<td>1.0-3.0</td>
</tr>
<tr>
<td>Forest residues (GROT) (1)</td>
<td>5.14-5.56</td>
<td>45-60</td>
<td>1.67-2.50</td>
<td>250-400</td>
<td>0.7-0.9</td>
<td>1.0-3.0</td>
</tr>
<tr>
<td>Wood waste (1)</td>
<td>5.28</td>
<td>15-35</td>
<td>3.3-4.4</td>
<td>150-250</td>
<td>0.61-0.81</td>
<td>3-16</td>
</tr>
<tr>
<td>Pellets (1)</td>
<td>5.28-5.33</td>
<td>8-10</td>
<td>4.67</td>
<td>650-750</td>
<td>3.06</td>
<td>1.5</td>
</tr>
<tr>
<td>Briquettes (1)</td>
<td>5.28-5.33</td>
<td>8-10</td>
<td>4.81</td>
<td>650-750</td>
<td>3.06</td>
<td>1.5</td>
</tr>
<tr>
<td>Garbage/waste materials</td>
<td></td>
<td>50</td>
<td>2.5-3</td>
<td>200</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>Peat</td>
<td>5.83</td>
<td>40-60</td>
<td>2.78-3.33</td>
<td>340-390</td>
<td>0.78-0.86</td>
<td>2-9</td>
</tr>
</tbody>
</table>

(1) Net calorific values as received are calculated on the net calorific value of the dry basis according to CEN/TS 15234. Calculation is presented in the following equation [9]:

\[ q_{\text{net,ar}} = q_{\text{net,d}} \times \left( \frac{100 - M_{\text{ar}}}{100} \right) - 0.02443 \times M_{\text{ar}} \]

where

- \( q_{\text{net,ar}} \) is the calorific value as received (MJ/kg)
- \( q_{\text{net,d}} \) is the net calorific value in dry matter (MJ/kg)
$M_{ur}$ is the moisture content as received (w-%)

0.02443 is the correction factor for the enthalpy of vaporization (constant pressure) for water (moisture) at 25 °C [MJ/kg per 1 w-% of moisture].

A comparison of the average calorific values is shown in Fig. 4. In Fig. 5 the moisture content of the biofuels of study is shown. A comparison of the bulk density and the energy density as received is shown in Fig. 6 and Fig. 7.

Fig. 4. Comparison of the average calorific values of the biofuels of study
By comparing Fig. 4 and Fig. 5, it is noticeable that while the net calorific value in dry content is similar for the wood fuels, the net calorific value as received varies much more, according to the moisture content of each fuel. As it has been said before, the higher the content of moisture, the smaller the heating value of the fuel. That is the reason why bark and grot as received, the biofuels which have the highest moisture value, have also the lowest calorific values.
Pellets and briquettes are the most compact wood fuels, therefore, the cost for transportation will be the lowest one.

The characteristics of each of the biofuels of study are the following [8].

**Bark**

Bark is characterised by irregular particle size and higher ash content than stem wood. It also has high moisture content. It has high potassium content and the nitrogen content is higher than in stem wood. The ash can be reused as fertilizer. It is suitable for FB, CFB and grate boilers. Moist bark should normally be consumed within a month or two after is has been stacked on a pile if spontaneous ignition and working environment problems are to be avoided.

**Forest Residues**

The forest residues are characterised by high moisture content and higher ash content than stem wood. Impurities can be found, both in the fuel and from accompanying materials. The ash can be reused as fertilizer. They are suitable for FB, CFB and grate boilers.
Wood Waste

Waste wood is cheaper than other wood fuels. It is characterised by irregular particle size and elevated content of ash and impurities. The ash may be polluted with heavy metals and may therefore have to be deposited as landfill or treated before reuse as fertilizer or other uses. It is suitable for FB, CFB and grate boilers, as well as for waste and co-combustion plants.

Pellets and Briquettes

Processed wood fuel is characterised by uniform particle size and good transport and feed properties. It also has better storage properties than other fuels. As said before, pellets are the most compact form of solid biofuel, therefore the transport cost per energy unit is the lowest. However, pellets and briquettes are more expensive to purchase, as they have to be processed, which involves energy consumption. The ash can be reused as fertilizer. Pellets and briquettes are suitable for all kind of boilers.

Garbage/Waste Materials

The calorific value of the waste depends on its composition. (I need to gather more data from Gästrike Återvinnare). The choice of MSW treatment for a particular locality must take into account, among other things, the composition of the input waste, the available technologies, and the market for the various outputs [10].

Peat

Peat is characterised by low density and high ash content. It has high nitrogen and sulphur contents. The ash can be reused as fertilizer. It is suitable for all types of boilers. The mixing of peat with wood fuels often reduces the problems of deposits and corrosion in the boiler.
2.3. Price of biofuels, peat and waste

In the Nordic countries fuel suppliers are paid according to the energy content of the delivered chips. For measuring the energy content of the delivered chips each truckload is weighed at the plant, and samples are taken for defining the moisture content. Based on the weight of the load, the moisture content, and the net calorific value of the chips, the energy content of each delivered load can be calculated [11].

In Sweden statistics for fuel prices are available for wood fuels. The information is based on data from about 10 district heating utilities and about 20 industries.

In table 2 the prices of woody biofuels from 2004 to 2007 are shown. For the prices of 2007 also a differentiation between different regions of Sweden is shown, as well as the prices in the quarters of the year.

Table 2. Woody fuel prices, SEK/MWh excluding taxes. [12]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sweden</td>
<td>North Sweden</td>
<td>Middle Sweden</td>
<td>Other regions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pellets and briquettes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating utilities</td>
<td>206</td>
<td>204</td>
<td>211</td>
<td>244</td>
<td>277</td>
<td>230</td>
<td>236</td>
<td>236</td>
</tr>
<tr>
<td>Wood chips</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industry</td>
<td>125</td>
<td>121</td>
<td>119</td>
<td>128</td>
<td>-</td>
<td>-</td>
<td>129</td>
<td>126</td>
</tr>
<tr>
<td>Heating utilities</td>
<td>138</td>
<td>137</td>
<td>146</td>
<td>158</td>
<td>167</td>
<td>142</td>
<td>153</td>
<td>167</td>
</tr>
<tr>
<td>By-products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industry</td>
<td>112</td>
<td>95</td>
<td>112</td>
<td>153</td>
<td>-</td>
<td>-</td>
<td>148</td>
<td>145</td>
</tr>
<tr>
<td>Heating utilities</td>
<td>114</td>
<td>121</td>
<td>128</td>
<td>134</td>
<td>128</td>
<td>127</td>
<td>120</td>
<td>145</td>
</tr>
<tr>
<td>Wood waste</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating utilities</td>
<td>74</td>
<td>80</td>
<td>78</td>
<td>64</td>
<td>69</td>
<td>51</td>
<td>69</td>
<td>58</td>
</tr>
</tbody>
</table>

1. The regional accounts comprise only data for heating utilities. Observe that average prices for the different regions are more uncertain than average prices for the whole country.
2. Not enough data for defining an average value.
3. Gävle is included in this region.
R. Information has been revised since price sheet 4/2007
P. Preliminary information
In table 3, the same information for peat is shown.

Table 3. Peat prices, SEK/MWh excluding taxes. [12]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sod peat (Stycketorv)</td>
<td>Heating utilities</td>
<td>110</td>
<td>126</td>
<td>118</td>
<td>120</td>
<td>132</td>
<td>131</td>
<td>133</td>
<td>-&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Milled peat (Frästorv)</td>
<td>Heating utilities</td>
<td>116</td>
<td>116</td>
<td>105</td>
<td>116</td>
<td>126</td>
<td>124</td>
<td>134</td>
<td>-&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

1. Same note as in table a.
2. Not enough data for defining an average value.
3. Gävle is included in this region.
4. Information has been revised since price sheet 4/2007
5. Preliminary information

In Figs. 8 and 9 a comparison of the prices from year 2003 to 2007, as well as for the quarters of year 2007 is shown.

![Price of biofuels and peat 2003-2007](image)

Fig. 8. Price of woody biofuels and peat from year 2003 to year 2007.
As it can be seen in the Figs. 8 and 9, the prices of the fuels remain pretty constant over the years, with refined biofuels (pellets and briquettes) being the fuels which most increase their price.
Data from other sources also show that prices of biofuels are not changing very much over the years. For instance, in Fig. 10 the change in prices from year 1993 to year 2002 are shown. The biofuels which change more the prices are, as in the latest data, refined biofuels.

The data for the prices are statistical data. However, fuel prices paid by individual plants, or for imported biofuels on the other hand, are difficult to obtain since the district heating companies act on a competitive market [4].

In Fig. 11 prices of different fuels in Sweden, including taxes, from 1970 to 2006 are shown. Compared with fossil fuels, wood chips price remain more or less constant, with an increase in the last year.

Fig. 11. Nominal commercial energy prices in Sweden, including tax, 1970-2006 (Source: Energy in Sweden 2007)

Fuels’ competitiveness is not only defined by their price. There are other factors that have to be taken into account, as associated investment costs, fuel flexibility, operation and maintenance costs. For district heating companies it is also important to have a security of supply, as the possibility to switch to other biofuels is often limited [4].
An average price for the waste is difficult to obtain, since the waste incineration tax is different in each case, and the prices are also dependant of the transportation distance. However, waste is the cheapest source of energy, even it is affected by the waste incineration tax, the CO\textsubscript{2} tax and the NO\textsubscript{2} tax. The waste incineration company gets paid for incinerating the waste, therefore, it does not have to pay a price for its fuel. Instead, it receives money for getting rid of the waste.

An average value for the price of the waste would be in the range between -300 and -500 kr per ton [13]. Considering the heating value of waste as 3 MWh/ton, the value of the price would be between -100 and -170 kr per MWh. It should be born in mind that these values are average prices for the whole country, and that prices for individual plants are more difficult to obtain, since they act in a market in competition.
3. Environmental issues

Combustion of woody biofuels and waste leads to emission of different pollutants to the atmosphere. In this section the environmental issues concerning combustion of the biofuels of study are discussed. Firstly, CO$_2$ emissions from the biofuels are explained. Other important emissions, such as NO$_x$, sulphur and dust are depicted in the following section. Finally, ashes and their pollution degree are also considered.

3.1. CO$_2$ emissions

Power generation and transportation are two of the largest sources of CO$_2$ emissions when using fossil fuels. Incineration of renewable fuels does not contribute to CO$_2$ emissions, as these fuels are considered CO$_2$ neutral. However, their usage in power plants has indirect emissions due to transportation of the fuels to the plant.

Woody biofuels incineration

When woody biofuels are managed in a sustainable way, they do not contribute directly to CO$_2$ emissions, since when they are growing they absorb the same amount of CO$_2$ emitted when they are burnt. An example of the cycle of CO$_2$ when using woody biofuels can be seen in Fig. 12.
The CO$_2$ emitted when burning woody biofuels is non-fossil CO$_2$. However, the usage of these fuels implies indirect emissions of CO$_2$ to the atmosphere, by means of transportation of the fuels to the combustion facility.

**Peat incineration**

In April 2006, the UN Climate Advisory body IPCC decided to abandon the concept of peat as a fossil fuel. Instead, it is defined as a slowly renewable biofuel [15].

According to a study published by IVL Swedish Environmental Research Institute, the CO$_2$ emission factor for peat is of 105-108 g/MJ fuel, for peat with about 45-50% moisture content. However, the emission factor is dependent on the moisture content of the fuel, therefore, peat with lower moisture content will have a lower CO$_2$ emission factor [16].
Waste incineration

There is no fixed definition of biofuel, nor how large a percentage of waste can be considered biofuel. In the 1990s, the Swedish Biofuel Commission found that approximately 85% of waste could be considered biofuel. However, this has not been proved once and for all. There are several statutory documents, such as EC directives, ordinances and regulations, and even various standards and proposals etc., in which the term biofuel is used in different ways [6].

According to the RVF (Swedish Association of Waste Management) report: Waste-to-Energy incineration – Greenhouse gas emissions compared to other waste treatment and energy production [6], the fossil combustible content of all incoming waste for incineration is approximately 14% by weight. The renewable content in the waste amounts to around 70% of the total weight of the waste. The remaining weight, approximately 15%, comprises inert material such as metal and gravel. Of the fossil content, soft and hard plastic are predominant in household waste, and mixed plastic is predominant in industrial waste. The inert fraction does not contribute to CO₂ emissions.

With the above results in mind, RVF believes that waste should be considered biofuel to a degree of 85%. Conversely, RVF also believes that the proportion of fossil combustible waste can be taken as 15% [6].

RVF believes that the CO₂ factor for waste incineration should be 25 g/MJ fuel. However, the Swedish Environmental Protection Agency uses a factor of 32.7 g/MJ fuel [6].

Choosing the option of incineration of waste, landfill disposal is being avoided, therefore, the emissions that would arise from the landfill are also avoided. Methane, one of the gases released in landfills’ decomposition process, is 20-times more potent greenhouse gas than carbon dioxide; therefore, landfill gases are considered to contribute more significantly to global warming than the net CO₂ emissions from incineration plants. This is represented in Fig. 13. Although waste incineration produces emissions of greenhouse gases, it avoids the emissions of a bigger amount of greenhouse gases, by means of other treatments, for example landfill disposal.
Besides the direct emission of CO$_2$ emissions, indirect emissions due to transportation issues should be also born in mind, when considering the total contribution of waste incineration to the levels of CO$_2$ released into the atmosphere.

3.2. Other emissions

Woody biofuels incineration

Considering the effects of wood combustion for health, particulate matter is the air pollutant of highest concern. Especially very small diameter particles are hazardous for human health, namely PM10 and PM2.5. Wood combustion facilities have much higher emissions of particulate matter than corresponding gas and oil systems. For this reason it is very important to have appropriate systems for cleaning the exhaust gases before releasing them to the atmosphere.

Other emissions from woody biomass combustion include [17]:

- Sulphur oxides (SO$_x$): they cause acid rain. Nowadays, emissions from woody biofuels combustion plants are much smaller than the emissions from oil combustion plants.
- Nitrogen oxides (NO\textsubscript{x}): they lead to the formation of ozone, smog, and are responsible for respiratory problems. Wood and fuel oil combustion have similar NO\textsubscript{x} emission levels.

- Carbon monoxide (CO): the proportion of CO formed during combustion depends on the system efficiency, but is significantly higher than during combustion of oil.

- Volatile organic compounds (VOCs): Some of these pollutants are toxic and other are carcinogenic. VOCs lead to formation of ozone, smog, and are responsible for respiratory problems. Woody biofuels combustion has higher emissions of some of these pollutants, while lower emission of others.

Waste incineration

Waste incineration is part both of the waste management system and the energy system in Sweden. By the year 2006, about 47% of household waste went to incineration.

Table 4 summarizes the emissions to air from waste incineration from 1985 to 2004, showing the great reduction in the emissions in that period of time.
Table 4. Emissions to air from waste incineration 1985-2004 [18]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen oxides (tons/year)</td>
<td>3 400</td>
<td>1 463</td>
<td>1 707</td>
<td>-50%</td>
</tr>
<tr>
<td>Sulphur (tons/year)</td>
<td>3 400</td>
<td>1 121</td>
<td>337</td>
<td>-90%</td>
</tr>
<tr>
<td>Particulates (tons/year)</td>
<td>420</td>
<td>33</td>
<td>24</td>
<td>-94%</td>
</tr>
<tr>
<td>Hydrogen chlorides (tons/year)</td>
<td>8 400</td>
<td>412</td>
<td>101</td>
<td>-99%</td>
</tr>
<tr>
<td>Mercury (kg/year)</td>
<td>3 300</td>
<td>77</td>
<td>37</td>
<td>-99%</td>
</tr>
<tr>
<td>Cadmium (kg/year)</td>
<td>400</td>
<td>8</td>
<td>5</td>
<td>-99%</td>
</tr>
<tr>
<td>Lead (kg/year)</td>
<td>25 000</td>
<td>214</td>
<td>54</td>
<td>-99.8%</td>
</tr>
<tr>
<td>Dioxins (g/year)</td>
<td>90</td>
<td>2</td>
<td>0.7</td>
<td>-99.2%</td>
</tr>
<tr>
<td>Waste incinerators (number of plants)</td>
<td>18</td>
<td>N/A</td>
<td>29</td>
<td>+61%</td>
</tr>
<tr>
<td>Incinerated waste (million tons)</td>
<td>N/A</td>
<td>1.7*</td>
<td>4.1**</td>
<td>+141%</td>
</tr>
<tr>
<td>Energy produced (TWh)</td>
<td>N/A</td>
<td>4.3*</td>
<td>11.5**</td>
<td>+167%</td>
</tr>
<tr>
<td>Recovered materials (household waste, 1000 tons)</td>
<td>N/A</td>
<td>580</td>
<td>1 658**</td>
<td>+186%</td>
</tr>
</tbody>
</table>

Source: Swedish EPA

*1994 **2006

At the high temperature at which the waste is incinerated in the plants, 90-95% of the dioxins in the waste are broken down into carbon dioxide, water and hydrogen chloride. A small quantity of the dioxins in the incoming waste is found in slag and bottom ash. Dioxins are also found in fly ash.

Emissions of dioxins from Swedish waste incineration plants have decreased dramatically, from 90 g/year in 1985 to 0.8 g/year in 2006 [19].

Although the amount of waste incinerated is increasing every year, the emissions of dioxins and metals from incineration plants have decreased significantly. This is the result of better cleaning of flue gases, better incineration conditions, and lower levels of metals in the incinerated waste.

Moreover, dioxins recovered after flue gas cleaning, which are collected in ash from the flue gas cleaning system; and especially dioxins in slag and bottom ash are solidly fixed to particles, and many studies have shown that separate handling gives rise to practically no leaching at all [20].

The results of the study of RVF in the report “Waste-to-energy, an inventory and review about dioxins”, are summarized as: “The study shows that dioxins found in the residual
waste from incineration are solidly fixed. This breaks the ecocycle of the dioxins in the waste. Incineration and energy production using waste as the fuel is a good way of dealing with combustible waste” [20].

3.3. Ash handling

Ashes are the rest product after the combustion, and they consist of non-combustible inorganic components. In biofuels we can differentiate between the inherent inorganic material and the extraneous inorganic material. The inherent inorganic material is part of the organic structure of the fuel; it is associated with the oxygen, sulphur and nitrogen-containing functional groups. The extraneous inorganic material is that material which has been added to the fuel in the processes of collection, handling and storage; as biomass fuels are usually mixed with soil and other materials during those processes.

The content of ashes in biofuels has an effect in the process of combustion. Some of the important issues to take into account are the following [21]:
- Formation of fused or partly-fused agglomerates and deposits in the boiler at high temperatures.
- Formation of bonded ash deposits at lower temperatures on surfaces in the convective sections of the boiler.
- Corrosion of the components of the boiler under ash deposits, and impact erosion or abrasion of the boiler components.
- Ash impact on the performance of the flue gas treatment equipment.
- Handling and disposal of ash residues from biofuel combustion plants.

Some of the biofuel actors are recycling the ash back to the forest. According to Swedish regulations this cannot be done if the ash has too high content of $^{137}\text{Cs}$ or too high content of heavy metals (Møre & Lynn, 2005; Samuelsen, 2001). Wood fuels from some regions in Sweden might generate both bottom ash and fly ash with too high content of $^{137}\text{Cs}$ (Møre & Lynn, 2002). The content of $^{137}\text{Cs}$ in wood and bark correlates with the $^{137}\text{Cs}$ content of the soil at the growth place [7]. $^{137}\text{Cs}$ should be lower than 10 kBq/kg dry substance [22].
4. Legislation and measures

4.1. Legislation

4.1.1. EU directives

In this section, an overview of the EU Directives which affect the biofuels for district heating is shown. Some of them have higher impact on the use of biofuels than others [3], [11], [23].


Under the RES Directive, many European countries have adopted policies that encourage the generation of useful energy from biomass.

For Sweden, the indicative targets (obligation quota) for electricity from renewable sources under the RES directive are:

<table>
<thead>
<tr>
<th>RES-E % in 1997</th>
<th>RES-E % in 2002</th>
<th>RES-E % in 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>49.1</td>
<td>46</td>
<td>60</td>
</tr>
</tbody>
</table>

In Sweden the policies to promote bioelectricity production are mainly quota and tradable certificates. These measures have had a positive impact on the use of biofuels in district heating production.

- **Landfill Directive (1999/31/EC)**

Thanks to the landfill directive, the amount of biodegradable waste destined to landfill disposal is reducing. The most used alternatives are waste incineration, mechanical-biological treatment and composting.


The ETS directive encourages the generation of energy from biomass in installations covered by the ETS. One of the three flexible mechanisms under the Kyoto Protocol is the International Emissions Trading (IET). By this system, each member state sets a
ceiling for its permitted national emissions, assessed by the European Commission, which give details of the total number of emission allowances that the state intends to allocate. One tonne of carbon dioxide corresponds to one emission allowance unit (EAU). If one company emits a bigger amount of CO$_2$ than the correspondent to its emission allowances, it has to buy the necessary allowances. On the other hand, companies whose emissions are less than their allowances can sell their remaining allowances. The International Trading in Emission Allowances starts in 2008, however, in the EU an emissions trading scheme started in 2005, as a preparation for the global trading under the Protocol.

- **Biofuels Directive (2003/30/EC)**

The biofuels Directive is leading to a considerable increase in demand for biomass for conversion to biofuels for transport. In the near future it may be practicable to produce biofuels for transport from wood for other purposes than heat and electricity generation, which would cause an even bigger increase in the demand for biomass.

In this sense, there is competition between biofuel policies and bioenergy policies. Although this directive has nothing to do with the production of district heating from biofuels, it does affect the demand for biomass, which is an important factor in the availability of biomass resources for district heating production.


- **IPPC (Integrated Pollution Prevention and Control) Directive (96/61/EC)**

The last three directives have an impact on the emission restrictions in bioenergy plants.
4.1.2. Implementation of the EU directives in Sweden

Source: [23].


The directive is completely translated into Swedish legislation, through the Electricity Certificate Act 2003:113 and the Electricity Certificate Ordinance. The result is the Electricity Certificate System, which is explained in the next section.

- **Landfill Directive (1999/31/EC)**

The directive is incorporated into Swedish legislation, through the Landfill of Waste Ordinance (NFS 2001:512). There is a timetable for knowing when the different fractions of waste are banned on landfills. By 31 December 2008 the actions should be implemented according to the plan.


The directive has been partly implemented in Swedish legislation, through the Law of CO$_2$ emissions (“Lag om utsläpp av koldioxid”, SFS 2004:656) and the Ordinance of CO$_2$ emissions (“Förordning om utsläpp av koldioxid”, SFS 2004:657); which came into force 1 August 2004.

The EU guidelines on monitoring and reporting have been implemented in regulation of the Swedish Environmental Protection Agency (EPA) (NFS 2004:9).

- **Biofuels Directive (2003/30/EC)**

The directive is being implemented in Swedish legislation (SOU 2004:133).


The fundamentals of the directive are implemented in the public report 2002:1060 and guidelines SOU 2002:28 (Swedish public reports).

The directive is completely implemented in Swedish legislation since 14 November 2004. There are lower emission limits for new built sites (built after 27 November 2003). If an existing site expands by more than 50 MW, it is also considered as a new site, and the lower emission limits are also applied in this case. If the air treatment equipment cease to work and does not start within 24 hours, combustion in the plant has to be limited or stopped.

- **IPPC (Integrated Pollution Prevention and Control) Directive (96/61/EC)**


### 4.2. Sweden´s energy policy

Sweden’s energy policy focuses on renewable energy sources and improvements in the efficiency of energy use as priority working areas.

In Sweden there are a number of regulations that boost the generation of energy from renewable sources. The success of bioenergy in Sweden lies on the use of policy instruments and incentives including financial support [3].

On the one hand, there are **Administrative policy measures**, which imply prohibitions or requirements, issued by political or administrative bodies. These measures are:
- Regulations
- Limit values for emissions

On the other hand, there are **Economic policy measures**, which affect the costs and the benefits of different possibilities in energy production. These measures are:
- Emission allowance trading
- Electricity certificate system
- Taxes
4.2.1. Administrative policy measures

- Limit values for emissions

In tables 5 and 6 the emissions limits at EU-level are shown, according to the directives:

Table 5. Emission limits mg/Nm³ for current/old establishments (waste incineration facilities do not have differenced rules) [23]

<table>
<thead>
<tr>
<th>Emission Directive</th>
<th>NOₓ</th>
<th>SO₂</th>
<th>Dust</th>
<th>Hg</th>
<th>Cd+Tl</th>
<th>CO</th>
<th>Dioxin</th>
<th>HCl</th>
<th>HF</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCP 50-350 MW²</td>
<td>600</td>
<td>0,19</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCP 350-500 MW²</td>
<td>600</td>
<td>100-400</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCP&gt;500 MW²</td>
<td>500³</td>
<td>400</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste</td>
<td></td>
<td></td>
<td>0,05</td>
<td>0,05</td>
<td>0,1³</td>
<td>10⁷</td>
<td>19⁷</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. 6% O₂, all for new plants, unless otherwise indicated
2. Type of fuel: solid
3. As of 1 Jan 2016 this will decrease to 200 mg per Nm³
4. The used fuel may not contain sulphur, if the combustion lead to SO₂ emissions it may not be more than the equivalent of 0,19 g sulphur per MJ fuel
5. Linear decrease regarding solid fuels
6. Municipal solid waste
7. Emission limit values for CO can be set by the competent authority
8. including furans
9. Total emission limit values for cement kilns, daily average values for other

Table 6. Emission limits mg/Nm³ for new establishments (LCP) [23]

<table>
<thead>
<tr>
<th>Emission Directive</th>
<th>NOₓ</th>
<th>SO₂</th>
<th>Dust</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCP 50-100 MW</td>
<td>400³</td>
<td>200³</td>
<td>50⁴</td>
</tr>
<tr>
<td>LCP 100-300 MW</td>
<td>300³</td>
<td>200³</td>
<td>30⁴</td>
</tr>
<tr>
<td>LCP&gt;300 MW</td>
<td>200³</td>
<td>200³</td>
<td>30⁴</td>
</tr>
</tbody>
</table>

1. 6% O₂, all for new plants, unless otherwise indicated
2. Type of fuel: biomass
3. Type of fuel: solid
In table 7 the emission limits for Sweden are shown.

Table 7. Emission limits mg/m$^3$ for Sweden, new large scale plants (>5 MW) [23]

| Emission Directive | NO$_2$ | SO$_2$ | Dust | CO | Hg | Cd | Dioxin | HCl | HF | C | Sb | As | Pb | Cr | Co | Cu | Mn | Ni | V | Sn | As, Cd, Co, Cr |
|--------------------|-------|-------|------|----|----|----|--------|-----|----|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| LCP- solid material | 200   | 200   | 30   |    |    |    |        |     | 0.1| 0.05/0.1 | 0.1 | 10 | 10 | 0.5 | 1.5/1.0 |
| Waste incineration  | 200   | 50    | 10   | 50 | 0.1| 0.1| 10     |     | 10 | 10 | 0.5 | 1.5/1.0 |

1. 6% O$_2$, all for new plants, unless otherwise indicated
2. The values correspond with the ones in table b

### 4.2.2. Economic policy measures

#### 4.2.2.1. Electricity certificate system

By this regulation the production of “green” electricity is encouraged. The system was introduced in 2003, and it has the aim of increasing the use of electricity from renewable sources by 17 TWh between 2002 and 2016. For each MWh of electricity produced from renewable sources the producer gets one certificate. All renewable sources are covered, except from hydroelectric power and the renewable fraction of waste. The reason is that if they were to be included the certificate market would be saturated, with the consequent certificate prices drop.

The producers of “green” electricity are controlled by the Swedish Energy Agency. The producer must measure the “green” electricity following a certain standard, in order to be approved by the agency.

Of the biofuels considered in this study, woody biofuels are renewable sources considered into the Electricity Certificate System, therefore, it is possible to get the electricity certificates by using these materials as biofuels. Peat is also considered into the system. Waste, however, is not considered into the scheme, and therefore cannot benefit from this system.
4.2.2. Taxes

In Sweden there is a CO$_2$ tax for the all fuels except biofuels and peat. It was introduced in 1991, and has had the result of the usage of biofuels being more profitable than fossil fuels. The tax to be paid is of 93 öre/kg CO$_2$ (value for 2007).

In 1992 a NO$_x$ tax was introduced. Its value is of 40 SEK/kg NO$_x$, and it is applied to emissions from boilers, gas turbines and stationary combustion plant supplying at least 25 GWh per annum. Therefore, independent of the biofuel of the study, the NO$_x$ tax must be paid.

In 1991 a sulphur tax was introduced. Its value is 30 SEK/kg of sulphur emitted from coal and peat.

In 2006 a tax was imposed on the incinerated waste with energy recovery. The tax is levied on domestic waste only. It encourages recycling and combined heat and power generation. The tax is calculated by a model depending on the amount of fossil material. The tax also depends on whether the plant produces only heat or both heat and electricity, and how effective the production of electricity is. For incineration plants without electricity production the tax is currently 451 kr/ton. The more electricity is produced the smaller the tax. At a 15% electricity recovery rate, the tax is approximately 77 kr/ton and at a 20% electricity recovery rate, the tax is 70,5 kr/ton [19].

Woody biofuels considered in this study are CO$_2$ tax exempt, as well as peat. Waste, on the other hand, is not exempt from the CO$_2$ tax. The NO$_x$ tax must be paid independent of the biofuel considered in this study. The sulphur tax must be paid in the case of peat, not in the case of woody biofuels and waste. The waste incineration tax is only paid for the household waste.

4.3. Impact of EU legislation and national policy measures

In table 8 it is shown which directives and policies affect each of the fuels of study, and whether the effect is positive or negative.
Table 8. Impact of EU legislation and national policy measures on the biofuels of study

<table>
<thead>
<tr>
<th>Affecting directive or policy</th>
<th>Woody biofuels</th>
<th>Waste</th>
<th>Peat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effect</strong></td>
<td><strong>Impact</strong></td>
<td><strong>Effect</strong></td>
<td><strong>Impact</strong></td>
</tr>
<tr>
<td><strong>RES directive</strong></td>
<td>Positive</td>
<td>Encourages the use of renewable sources.</td>
<td>Positive</td>
</tr>
<tr>
<td>Landfill directive</td>
<td>Indifferent</td>
<td></td>
<td>Positive</td>
</tr>
<tr>
<td><strong>ETS directive</strong></td>
<td>Positive</td>
<td>Combustion of woody biofuels leads to lower emissions of CO₂.</td>
<td>Positive</td>
</tr>
<tr>
<td>Biofuels directive</td>
<td>Negative</td>
<td>Competition between use of woody biofuels for CHP and use for production of biofuels for transport.</td>
<td>Indifferent</td>
</tr>
<tr>
<td>Waste incineration directive</td>
<td>Indifferent</td>
<td></td>
<td>Negative/Positive for environment</td>
</tr>
<tr>
<td>Electricity certificate system</td>
<td>Positive</td>
<td>Encourages the use of renewable sources.</td>
<td>Indifferent</td>
</tr>
<tr>
<td>CO₂ tax</td>
<td>Positive</td>
<td>Woody biofuels are CO₂ tax exempt.</td>
<td>Negative</td>
</tr>
<tr>
<td>NO₂ tax</td>
<td>Negative</td>
<td>Woody biofuels are not NO₂ tax exempt.</td>
<td>Negative</td>
</tr>
<tr>
<td>Sulphur tax</td>
<td>Positive</td>
<td>Woody biofuels are sulphur tax exempt.</td>
<td>Positive</td>
</tr>
<tr>
<td>Waste incineration tax</td>
<td>Indifferent</td>
<td></td>
<td>Negative</td>
</tr>
</tbody>
</table>
5. Description of the power and heat production in Gävle

In Fig. 14 the power and heat production in Gävle municipality is shown.

![Diagram](image)

Fig. 14. Power and heat production in Gävle municipality.

Gävle Energi is a company which supplies electricity and heat for the municipality of Gävle. It has a wide district heating network in the majority of the municipality. The district heating network has about 260 km of length for both hot supply water pipe and cool return water pipe. The system has about 4000 district heating substations.
In Johannes plant, owned by Gävle Energi, electricity and heat for the municipality of Gävle are produced. Heat is also produced in Korsnäs AB pulp mill. In Johannes the main fuels are woody biofuels (bark, forest residues and wood waste), while in Korsnäs the fuels are mainly by-products from pulp manufacture. The surplus heat from the production of paper is also used in the district heating network. When there are high peak loads of demand, for example during very cold winter days; or when a technical problem occurs in Johannes plant, two other plants are available for production of heat. These plants are Ersbo and Carlsborg, and they are operated with oil. The company has also seven hydro power plants with capacity between 0.32 and 3.8 MW of electricity, and a wind power plant with 0.6 MW capacity.
The approximate production of district heating for the municipality of Gävle is the following:

![Production of district heating in Gävle](image)

Fig. 16. District heating production in the municipality of Gävle Energi

In table 9 the fuels used in Gävle Energi facilities are summarized.

**Table 9. Fuel usage in Gävle’s energy system**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Utility</th>
<th>Power</th>
<th>Other comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woody biofuels</td>
<td>Johannes</td>
<td>77 MW</td>
<td>5520 hours/year operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Share of biofuels (% energy):</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Bark: 76.4 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Wood waste: 21.5 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Forest residues: 1.7 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Dry chipped: 0.4 %</td>
</tr>
<tr>
<td>Oil</td>
<td>Ersbo</td>
<td>2 boilers x 40 MW</td>
<td></td>
</tr>
<tr>
<td>Carlsborg</td>
<td></td>
<td>2 boilers x 30 MW</td>
<td></td>
</tr>
</tbody>
</table>
6. Method

6.1. Research planning

For the realization of the thesis, the first step has been the reading of literature concerning biofuels, peat and waste. In web pages there are the most important sources of information, as many of the reports from different institutions are available online. Internet sites have been an important source of information, mainly for the definition of the characteristics of biofuels, price of biofuels, environmental issues and legislation. They have also been useful when finding the companies responsible for the collection of waste, as well as wood related companies. Much of the contacts in the companies and industries have been found in the Internet.

The second step has been the calculation of the transportation cost of biofuels, which is explained with detail in Appendix 4. For this calculation, different sources have been used to try to calculate an average value.

With the transportation cost defined, a reasonable distance of transport is defined around the city of Gävle. The most important municipalities around Gävle are researched, in order to have an overall idea of the household waste resources useful for incineration in those municipalities. Industrial waste collection companies are also researched.

The most important actors of wood processing industries around Gävle are also researched, in order to get information about the resources of woody biofuels in the present and in the future.

6.2. Surveys/interviews

In order to get some important data for the thesis, a number of surveys have been sent to different companies and municipalities.

For defining the availability of biofuels, attention is drawn to big industries around Gävle that have by-products arising from their production processes. Questionnaires have been sent to these companies, in order to get data concerning the yearly amount of by-products useful for district heating production, as well as the properties of these fuels.
For defining the availability of waste, the waste collection responsible companies (in some cases the municipalities are responsible for the collection of waste) considered within a reasonable transportation distance have been sent a questionnaire concerning the collection of waste, and the properties of waste.

All the questionnaires sent to companies and municipalities are included in Appendix 1. Some of the companies did not answer the questionnaires, other companies answered part of the questionnaire. The obtained information is included in Appendix 2.

Apart from the surveys, personal interviews were conducted in Gästrike Återvinnare and SITA Sverige, in order to get the information of the amount of waste collected in Gävle and its surrounding municipalities. The obtained information is included in Appendix 2.

In summary, the interviewed companies are shown in table 10.

Table 10. Companies that have been interviewed or sent questionnaires.

<table>
<thead>
<tr>
<th>Pulp mills</th>
<th>Producers of biofuels</th>
<th>Household waste collection responsibles</th>
<th>Industrial waste collection companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korsnäs AB</td>
<td>Sydved AB</td>
<td>Gästrike Återvinnare</td>
<td>Stena recycling</td>
</tr>
<tr>
<td>Stora Enso AB</td>
<td></td>
<td>Bollnäs Kommun</td>
<td>Sita</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bollnäs Energi</td>
<td>Regn-Sells</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Söderhamn Vatten och Renhållning</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Falu Energi &amp; Vatten</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Borlänge Energi</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tierps Kommun</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uppsala Kommun</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vattenfall Varne Uppsala</td>
<td></td>
</tr>
</tbody>
</table>
7. Results

7.1. Transportation price of biofuels, peat and waste

When biomass is employed as a fuel for CHP plants, the availability of a stable and sufficient feedstock supply within a reasonable distance from the plant is essential [10].

The transportation issue is very important for the utilization of biofuels, due to the great amounts of biofuels necessary to equal the calorific value of other fuels. Transports longer than 50-100 km are not economically or environmentally viable, which means that terminals must be placed near power plants [24].

For the calculation of the price of transportation of the fuels, different sources have been used (see Appendix 3).

The calculated transportation cost value for the biofuels is:

\[
\text{Transportation Cost: } 0.75 - 0.8 \text{ kr/ton\cdot km}
\]

However, not all the fuels have the same heating value per ton, and the interesting value to compare is the price per MWh. The obtained values are shown in Table 11. A comparison of the price of transportation is shown in Fig. 17 as well.

<table>
<thead>
<tr>
<th>FUEL</th>
<th>Bark</th>
<th>Forest residues</th>
<th>Wood waste</th>
<th>Pellets</th>
<th>Briquettes</th>
<th>Waste</th>
<th>Peat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net calorific value as received (MWh/ton)</td>
<td>1.38-2.50</td>
<td>1.67-2.50</td>
<td>3.3-4.4</td>
<td>4.67</td>
<td>4.81</td>
<td>2.9</td>
<td>2.78-3.33</td>
</tr>
<tr>
<td>Transportation cost (kr/MWh\cdot km)</td>
<td>0.31-0.56</td>
<td>0.31-0.46</td>
<td>0.17-0.23</td>
<td>0.16</td>
<td>0.16</td>
<td>0.26</td>
<td>0.23-0.28</td>
</tr>
</tbody>
</table>
Compared with the calorific value of the fuels as received, it is clear that the higher the calorific value of the fuel, the lower is the transportation cost in an energy basis. That is the reason why pellets and briquettes, which have the highest calorific value, are the fuels cheapest to transport.

It should be born in mind that the transportation costs calculated for each of the fuels may change depending on the distance of transportation, and should not be considered as exact values.

### 7.2. Availability of biofuels in the region of Gävle

For the availability of woody biofuels in the area, big companies will be taken into account. The companies are:

- Korsnäs AB
- Stora Enso AB (Skutskär pulp mill)
- Sydved

In Fig. 18 the pulp mills of research are marked in pink. Pellet factories are also marked in the map in green color [25]. As an orientation for the distance, a radio of 100 km is defined around the municipality of Gävle.
Fig. 18. Availability of biofuels in the region of Gävle
In the plant of Skutskär, owned by Stora Enso, the amount of by-products (bark) produced in 2007 was 200000 wet tones. For the incoming years it is expected a similar level of production. Nevertheless, the company might burn more of the resulting by-products in their own boiler.

The data correspond with the source of Sydved. In Skutskär plant the amount of bark collected corresponds to about 550000 m$^3$ or 380000 MWh. With the average heating value of bark this amount corresponds to about 200000 tones.

The amount of bark is predicted to decrease by 70000 m$^3$ next year, as this quantity of bark is going to the own boiler of Skutskär. This amount corresponds to about 49000 MWh and 26000 tones of bark.
7.3. Availability of waste in the region of Gävle

Fig. 19. Radio considered for the availability of waste in the region of Gävle
For the availability of waste in the region of Gävle, a radio of 100 km is defined around the municipality of Gävle, according to Fig. 19.

For the availability of household waste, the biggest municipalities are taken into account for the research of data. These municipalities are marked in red in Fig. 19.
Firstly, the collection of waste in Gävle and its surroundings is the most important source of waste. Small municipalities around Gävle are also taken into account, since the same company is responsible for their waste collection. These municipalities are: Hofors, Ockelbo, Sandviken and Älvkarleby.
Secondly, other big municipalities in the area are researched. These municipalities are:
- Bollnäs
- Soderhamn
- Falun
- Borlänge
- Uppsala
- Sala
- Avesta

In Table 12 the population of the different municipalities and the companies responsible for the waste collection are shown. Sita Sverige and Ragn-Sells also collect waste from industries.

Table 12. Population and waste collection responsible companies in the different municipalities considered (data from 31/12/2007) [26], [27]

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Population</th>
<th>Waste collection</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gävle</td>
<td>92681</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hofors</td>
<td>10039</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ockelbo</td>
<td>5985</td>
<td>Gästrike Återvinnare</td>
<td></td>
</tr>
<tr>
<td>Sandviken</td>
<td>36804</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Älvkarleby</td>
<td>9095</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bollnäs</td>
<td>26217</td>
<td>Bollnäs Kommun</td>
<td></td>
</tr>
<tr>
<td>Soderhamn</td>
<td>26120</td>
<td>Söderhamn Vatten och Renhållning AB</td>
<td></td>
</tr>
<tr>
<td>Falun</td>
<td>55220</td>
<td>Falu Energi &amp; Vatten</td>
<td></td>
</tr>
<tr>
<td>Borlänge</td>
<td>47756</td>
<td>Borlänge Energi</td>
<td></td>
</tr>
<tr>
<td>Tierp</td>
<td>20068</td>
<td>Tierps Kommun</td>
<td></td>
</tr>
<tr>
<td>Uppsala</td>
<td>187541</td>
<td>Uppsala Kommun</td>
<td></td>
</tr>
<tr>
<td>Sala</td>
<td>21412</td>
<td>Sala Kommun/VafabMiljö</td>
<td></td>
</tr>
<tr>
<td>Avesta</td>
<td>21886</td>
<td>Avesta Kommun</td>
<td></td>
</tr>
</tbody>
</table>
Obtained data from Gästrike Återvinnare and Sita Sverige are presented below. Data from Ragn-Sells are not available.

Gästrike Återvinnare

Gästrike Återvinnare is a company which collects household waste and other types of waste from the municipalities of Gävle, Sandviken, Hofors, Ockelbo and Ålvkarleby.

The data of the amount of household waste they collected in the year 2007 are resumed in the Table 13:

Table 13. Amount of household waste collected by Gästrike Återvinnare in 2007 (tones)

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gävle</td>
<td>1310</td>
<td>1109</td>
<td>1611</td>
<td>1625</td>
<td>1722</td>
<td>1568</td>
<td>1627</td>
<td>1727</td>
<td>2033</td>
<td>2255</td>
<td>1559</td>
<td>1540</td>
<td>19686</td>
</tr>
<tr>
<td>Sandviken</td>
<td>1002</td>
<td>801</td>
<td>495</td>
<td>381</td>
<td>398</td>
<td>365</td>
<td>412</td>
<td>480</td>
<td>0</td>
<td>0</td>
<td>327</td>
<td>287</td>
<td>4948</td>
</tr>
<tr>
<td>Hofors</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>11</td>
<td>30</td>
<td>40</td>
<td>47</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>38</td>
<td>45</td>
<td>219</td>
</tr>
<tr>
<td>Ockelbo</td>
<td>75</td>
<td>59</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>144</td>
</tr>
<tr>
<td>Ålvkarleby</td>
<td>148</td>
<td>115</td>
<td>127</td>
<td>141</td>
<td>137</td>
<td>135</td>
<td>177</td>
<td>143</td>
<td>0</td>
<td>0</td>
<td>135</td>
<td>140</td>
<td>1398</td>
</tr>
<tr>
<td>Wet waste</td>
<td>69</td>
<td>58</td>
<td>69</td>
<td>56</td>
<td>86</td>
<td>74</td>
<td>89</td>
<td>117</td>
<td>59</td>
<td>83</td>
<td>73</td>
<td>67</td>
<td>900</td>
</tr>
<tr>
<td>Compost</td>
<td>581</td>
<td>512</td>
<td>573</td>
<td>566</td>
<td>627</td>
<td>589</td>
<td>549</td>
<td>581</td>
<td>596</td>
<td>757</td>
<td>737</td>
<td>779</td>
<td>7447</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3185</td>
<td>2654</td>
<td>2893</td>
<td>2769</td>
<td>2981</td>
<td>2761</td>
<td>2894</td>
<td>3095</td>
<td>2688</td>
<td>3095</td>
<td>2869</td>
<td>2858</td>
<td>34742</td>
</tr>
<tr>
<td>Combustible waste</td>
<td>2604</td>
<td>2141</td>
<td>2321</td>
<td>2203</td>
<td>2353</td>
<td>2172</td>
<td>2346</td>
<td>2513</td>
<td>2092</td>
<td>2338</td>
<td>2133</td>
<td>2078</td>
<td>27294</td>
</tr>
</tbody>
</table>

In Fig. 20 the monthly amounts of household waste and combustible waste collected by Gästrike Återvinnare in 2007 are shown. In Fig. 21 the amount of household waste and combustible waste collected by Gästrike Återvinnare in 2007 in a monthly accumulative basis is shown.
The average monthly collected amount of household waste is 2895 tones, and the average monthly value or the combustible part of the waste collected is 2292.

Nowadays Gästrike Återvinnare sends the combustible waste to the Korstaverket power plant, which is located in Sundsvall, for incineration.
Gästrike Återvinnare also collects other types of waste from households and industries, such as wood, chemically treated wood, metals, garden waste, hazardous waste, etc.

The two types of waste which can be used for CHP generation are wood and combustible waste; the monthly collected amounts are shown in Table 14 and represented in Figs. 22 and 23:

Table 14. Wood and combustible waste collected by Gästrike Återvinnare in 2007 (kg)

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>136160</td>
<td>104380</td>
<td>248220</td>
<td>393580</td>
<td>422080</td>
<td>420180</td>
<td>683020</td>
<td>538700</td>
<td>417160</td>
<td>474720</td>
<td>245480</td>
<td>630580</td>
<td>4714260</td>
</tr>
<tr>
<td>Comb. waste</td>
<td>337640</td>
<td>247700</td>
<td>446500</td>
<td>551280</td>
<td>559370</td>
<td>516660</td>
<td>735280</td>
<td>630000</td>
<td>582240</td>
<td>651200</td>
<td>477800</td>
<td>287700</td>
<td>6023370</td>
</tr>
</tbody>
</table>

Fig. 22. Monthly collected wood waste by Gästrike Återvinnare in 2007

Fig. 23. Monthly collected combustible waste by Gästrike Återvinnare in 2007
As can be seen in Figs. 22 and 23, the amount collected is not very stable over the months, so the value considered should be the total amount collected during the whole year.

In 2007 Gästrike Återvinnare collected 4714260 kg of wood waste, which were destined to recycling. Apart from that, they collected 3662360 kg more of wood, which were transported to Johannes plant for incineration. That makes an annual collection of 8376620 kg of wood waste in 2007. The amount of other combustible waste was 6023370 kg.

Most household waste that can be incinerated is transported to the Forsbacka waste station, where it is reloaded for further transport to Sundsvall.

The companies are responsible themselves for their waste from activities apart from household waste/rubbish, which is collected by Gästrike Återvinnare according to a particular subscription contract. For other waste which arises from other activities, there are different companies who can help with whole solutions for taking the waste into custody. Those private companies are Sita, Stenametall, etc. The waste is transported to Forsbacka waste dump, where it is sorted. In Fig. 24 the location of Forsbacka is shown.

Fig. 24. Location of Forsbacka waste dump [28]
SITA Sverige AB

SITA is a company which collects waste in the North part of Gävle, and in the surroundings north of Gävle. The company collects different types of waste:
- Household waste
- Industrial waste
- “Slam”

The industrial waste is mainly collected from big industries, which are Sandvik (around 40%), Korsnäs (around 25%) and Stora Enso (around 10%). The rest is collected from smaller industries.

The waste collected can be divided in four fractions:
- Wood
- Combustible waste
- Paper
- Construction materials (“Fyllnadsmassor”): Brick (“tegel”) etc.

Wood and combustible waste are destined to incineration. About 80% of these fractions go to Sundsvall incineration plant, and the remaining 20% goes to Uppsala incineration plant.

The amount of waste collected in 2007 was the following:
- Household waste: 26780 ton
- Industry waste: 24183 ton
- Wood waste: 9599 ton
These amounts correspond to the waste that goes to incineration.

The heating value of the waste that goes to incineration is about 2.5-3 MWh/ton.

The waste is transported to Forsbacka waste dump, where it is sorted. After that, the combustible waste goes to the incinerators, and the remaining fractions are destined to recycling and landfill disposal.
Other municipalities

The information about the waste collected in other municipalities is of less importance, as nowadays it is incinerated in other cities. Nevertheless, a summary of the data collected is shown in table 15.

Table 15. Waste collection data from other municipalities

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Amount of household waste collected in 2007 (ton)</th>
<th>Waste incinerated in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bollnäs</td>
<td>1</td>
<td>Bollnäs</td>
</tr>
<tr>
<td>Söderhamn</td>
<td>1</td>
<td>Bollnäs</td>
</tr>
<tr>
<td>Falun</td>
<td>Combustible: 4284</td>
<td>Borlänge</td>
</tr>
<tr>
<td>Borlänge</td>
<td>1</td>
<td>Borlänge</td>
</tr>
<tr>
<td>Tierp</td>
<td>Household waste: 4000</td>
<td>Uppsala</td>
</tr>
<tr>
<td></td>
<td>Waste wood: 2750</td>
<td></td>
</tr>
<tr>
<td>Uppsala</td>
<td>Combustible: 34979</td>
<td>Uppsala</td>
</tr>
<tr>
<td></td>
<td>Waste wood: 5672</td>
<td></td>
</tr>
</tbody>
</table>

1. Some of the data are not available, because the lack of answers from the companies
8. Discussion and conclusions

Concerning the physical properties of the fuels, the ones which have less moisture will have a higher calorific value, and therefore, a higher amount of energy per ton will be available from these fuels. As can be seen in Figs. 4 and 5, the fuels with less moisture are refined biofuels (pellets and briquettes), and therefore, they have also the highest heating value. They are followed by wood waste, which has more moisture. Finally, bark, grot, garbage and peat have a similar content of moisture and therefore, similar heating value. The moisture and the heating value of each of the fuels is shown in Figs. 25 and 26.

Fig. 25. Moisture content of the fuels of study

Fig. 26. Calorific value as received of the fuels of study
Bulk density and energy density are two factors affecting the price of transportation of the fuels. The heating value also affects the cost of transportation. In Fig. 27 the energy density of the biofuels of study is shown. It is noticeable the big difference between refined wood fuels and the rest of the fuels. Pellets and briquettes are the most compact fuels, therefore, they have the lowest transportation cost.

![Energy density as received](image)

Fig. 27. Energy density as received of the fuels of study

From the point of view of the physical properties of the fuels, the conclusion that can be drawn is that the best fuels for combustion are pellets and briquettes, and they will also have the lowest transportation cost. Bark and forest residues have the lowest calorific value as received. Wood waste, peat and waste materials have intermediate values.

Regarding price of the fuels, in Fig. 28 the average prices for different fuels are shown.

![Price of biofuels and peat 2003-2007](image)

Fig. 28. Price of woody biofuels and peat from year 2003 to year 2007.
The biofuels, listed from the cheapest to the most expensive, are:
- Waste
- Wood waste
- Peat
- By-products
- Wood chips
- Pellets and briquettes

With regard to the transportation cost of the fuels, this can be seen in Fig. 29.

![Transportation cost graph](image)

Fig. 29. Transportation cost of the fuels of study

From the point of view of price, the conclusion that can be drawn is that waste is the cheapest source of energy, followed by unrefined woody biofuels and peat. Refined woody biofuels, on the other hand, are the most expensive fuels, and even if their heating value is the highest, the price that has to be paid for energy unit does not compensate this. Even if the transportation cost is higher for woody biofuels, the calculated value should not be considered as exact, it is only an approximation to be able to compare the cost of transportation cost in an energy basis. Moreover, it should be born in mind that the transportation cost might change depending on the distance of transportation.

On the other hand, the price of the different fuels is not changing significantly over the years. Therefore it can be concluded that the prices of these fuels tend to remain more constant when compared to other fossil fuels, like petrol or natural gas. The fuels which are becoming more expensive are refined woody biofuels. This can be affected by international trade, and an increase in the demand for these fuels for small-scale heating facilities.
Concerning environmental issues, combustion of fuels leads to diverse emissions to the atmosphere.

First of all, if carbon dioxide emissions are taken into account, power and transportation are two of the largest sources of CO$_2$ emissions when using fossil fuels. In this aspect, woody biofuels are the most environmentally friendly fuels, as they are considered CO$_2$ neutral. Peat is not considered a renewable fuel nowadays. Instead, it is considered a slowly renewable biofuel. The CO$_2$ emission factor for peat is 105-108 g/MJ fuel. Waste has both renewable and non-renewable fractions. Studies suggest that approximately 85% of waste can be considered as biofuel. The CO$_2$ emission factor for waste is 32.7 g/MJ fuel.

With regard to other emissions, combustion of woody biofuels leads principally to emission of particulate matter, SO$_x$, NO$_x$, CO and VOCs. Combustion of waste leads also to emission of dioxins, which are really harmful pollutants. However, emissions of dioxins have decreased significantly in the last years, and with nowadays’ available technology incineration can be considered a good way to manage the waste.

Finally, it should be born in mind that the combustion of the fuels considered also lead to indirect emissions to the atmosphere, derived from the transportation to the fuels to the plant where they are burnt.

When burning solid fuels the ashes are also an issue to be considered. Handling of ashes is very important, and nowadays ashes can be recycled back to the forest. However, ashes with too high content of $^{137}$Cs cannot be recycled and have to be handled by other means.

Regarding legislation, there are a number of EU directives and national measures which affect the combustion of the fuels considered in the study.

Woody biofuels are positively affected by EU legislation, because they are considered renewable sources of energy. Moreover, the Swedish electricity certificate system encourages their use, which makes them more competitive nowadays. The fact that they are CO$_2$ tax, NO$_2$ tax and sulphur tax exempt also makes their use more profitable in the present.

In the case of peat, it is included in the electricity certificate system, which is positive. Although its combustion leads to CO$_2$ emissions, it is CO$_2$ tax exempt, which makes its
use more profitable than other fossil fuels. However, it is not exempt from NO₂ tax and sulphur tax, therefore, it has less advantages than woody biofuels in this sense.

Combustion of waste is nowadays encouraged principally thanks to the landfill directive. However, it is not exempt from NO₂ tax and sulphur tax. Moreover, there is a tax for waste incineration, and using waste as a fuel cannot benefit from the electricity certificate system. Therefore, it has less advantage than woody biofuels too.

Concerning availability of woody biofuels in the region of Gävle, the principal conclusion is that the source of fuel should not be placed far from the heating plant. Therefore, the most interesting actors will continue to be Korsnäs and Skutskär pulp mills. Even if there are some pellets producers within less than 100 km of distance, the price of these fuels is much higher than the by-products obtained from the pulp mills, and the transportation distance is even bigger.

It is difficult to predict the availability of woody biofuels in the future, since forest industries might change their activities. Even if next year more bark is going to be destined to incineration in the boiler of Skutskär, other forest actors could increase their activity in the forests nearby Gävle.

Regarding availability of waste in the region of Gävle, the conclusion that can be drawn is that, even if there are many municipalities from which waste could be transported to Gävle for incineration, these municipalities are currently transporting their combustible waste to incineration plants which are in a much shorter distance than Gävle. Therefore, much of the considered municipalities are ruled out from the initial list. Actually, the most realistic scenario is that the waste collected in households and industries near Gävle could be transported easily to a waste incineration plant within the municipality. Waste from other municipalities could also be incinerated in Gävle. These municipalities are the ones in which Gästrike Återvinnare and Sita Sverige collect waste currently.

The availability of waste in the future will be very similar to the one in the present, due to the little changes in population and consumption patterns in the area. Waste used to increase about 2% per year, being more stable during the last years.
9. Further work

Further research concerning the availability of biofuels in the area could consist in trying to define more exactly the sources of biofuels.

In the case of woody biofuels, other sources besides Korsnäs and Skutskär pulp mills could be researched. Moreover, in this study results about Korsnäs production were not obtained. Actually, there are companies that act as middlemen between the pulp mills and the district heating plants. Therefore, these companies are the one who actually have data regarding the availability of wood fuels in the area, as they not only collect by-products from the pulp mills, but from other sources, which are more difficult to define. Besides Sydved, which is the company researched in this study, there are other companies acting in Sweden that could provide fuel for the heating of Gävle, for instance, Neova [29] or Sodra [30].

In the case of peat, this study has not focused on its availability, but only in its physical properties, environmental issues and legislation. Further research could be focused on the availability of this fuel in the region. Moreover, some of the companies which trade with woody biofuels, also include peat in their purchase and sell activities.

In the case of waste, further research could include trying to define the fractions of waste, to have more valuable information about the real potential of the available waste in the region.
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Appendices

Appendix 1: Questionnaires sent to the companies

1. Questionnaire to household waste collection responsible companies or entities

COMPANY

If you could provide me with the most recent data, for example, data from year 2007.

QUESTIONS:

- What is done with the waste nowadays? What is done with the combustible fraction of the waste nowadays? Which are the incinerators that burn the combustible waste?

HOUSEHOLD WASTE

- How much waste is collected per year? In which municipalities?

- What is the combustible fraction of the waste collected in the different municipalities?

- What is the composition (percentages) of the combustible waste? For example, percentages of: paper, plastic, textiles, etc.

- What is the average heating value of the combustible waste?

INDUSTRY WASTE

- How much waste is collected per year from industries? From which industries?

- What is the combustible fraction of the waste collected in the industries?

- What is the composition (percentages) of the combustible waste? For example, percentages of: paper, plastic, textiles, etc.

- What is the average heating value of the combustible waste?
WASTE WOOD/DEMOLITION WOOD

- Do you collect any waste wood/demolition wood? (amount/year)

- What is the average heating value of the waste wood/demolition wood?

TRANSPORTATION

- What is the transportation price for the waste destined for incineration?

- Are there any special transportation needs?

PRICE

- How much do you have to pay to incinerate the waste?
  * Price of the waste
  * Incineration tax
  * Transportation cost

2. Questionnaire sent to industrial waste collection companies (Sita, Stena Recycling)

COMPANY

If you could provide me with the most recent data, for example, data from year 2007.

QUESTIONS:

- How much waste is collected per year from industries? From which industries? What is it done with the waste nowadays? The combustible waste is destined to incineration? In which combustion plant?

- What is the combustible fraction of the waste collected in the industries?
- What is the composition (percentages) of the combustible waste? For example, percentages of: paper, plastic, textiles, etc.

- What is the average heating value of the combustible waste?

**3. Questionnaire sent to pulp mills (Korsnäs, Stora Enso)**

**COMPANY**

If you could provide me with the most recent data, for example, data from year 2007.

**QUESTIONS:**

- Which quantities of sub-products useful for combustion (bark, wood waste…) are produced? (amount/year)

- What are the physical characteristics of the sub-products?
  * Calorific value
  * Moisture
  * Density
  * Ash quantity

- What is the price of these fuels?
  * Cost of the fuel (kr/ton) or (kr/MWh)
  * Cost of transportation of the fuel (kr/ton·km) or (kr/MWh·km)

- Where are the fuels transported?

- What will be the production in the next years be like? Is it going to increase, decrease, maintain the same level?
4. Questionnaire sent to Sydved

QUESTIONS:

- Which quantities of sub-products useful for combustion (bark, wood waste, industrial waste…) are collected? (amount/year)

- From which companies?

- What are the physical characteristics of the sub-products? (Maybe you don’t have the answers, I am also researching other sources)
  * Calorific value
  * Moisture
  * Density
  * Ash quantity

- What is the price of these fuels?
  * Cost of the fuel (kr/ton) or (kr/MWh)
  * Cost of transportation of the fuel (kr/ton·km) or (kr/MWh·km)
Appendix 2: Information from the companies

1. Gävle Energi

Table 1. Power summary. Year 2007

<table>
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<tr>
<th></th>
<th>District heating</th>
<th>Input Fuel-energy</th>
<th>Input Fuel-amount</th>
<th>Input Fuel-amount</th>
<th>Steam-Power boiler</th>
<th>Heat-Production condenser</th>
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<th>Boiler in operation</th>
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<tr>
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<td>Power to network</td>
<td>Total GWh</td>
<td>Solid fuel Ton</td>
<td>oil Ton</td>
<td>Production GWh</td>
<td>Production GWh</td>
<td>Production GWh</td>
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<td>2007-jan</td>
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<td>56.56</td>
<td>26591</td>
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<td>10.2</td>
<td>673</td>
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<td>27.7</td>
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<td>56.94</td>
<td>27939</td>
<td>6.291</td>
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<td>35.5</td>
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<td>255.6</td>
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Table 2. Emission summary. Year 2007.

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<tr>
<th></th>
<th>NOx emission mg/MJ</th>
<th>NOx flow Ton</th>
<th>NH3 emission mg/MJ</th>
<th>NH3 flow Ton</th>
<th>Sulphur emission mg/MJ</th>
<th>Sulphur flow Ton</th>
<th>Dust emission before FGC mg/Nm3</th>
<th>Dust flow before FGC Ton</th>
<th>CO emission mg/MJ</th>
<th>CO flow Ton</th>
<th>N2O emission mg/MJ</th>
<th>N2O flow Ton</th>
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Table 3. Feed into pocket from fuel storage. Year 2007.

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<tr>
<td>Jan</td>
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</tbody>
</table>

Table 4. Feed into pocket from lorry. Year 2007

<table>
<thead>
<tr>
<th></th>
<th>Feed into pocket from lorry</th>
<th>MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bark: ton</td>
<td>MWh</td>
</tr>
<tr>
<td>Jan</td>
<td>7156</td>
<td>14 779</td>
</tr>
<tr>
<td>Feb</td>
<td>7542</td>
<td>13 429</td>
</tr>
<tr>
<td>Mar</td>
<td>11 870</td>
<td>22 840</td>
</tr>
<tr>
<td>Apr</td>
<td>7521</td>
<td>15 484</td>
</tr>
<tr>
<td>May</td>
<td>19 17</td>
<td>4 791</td>
</tr>
<tr>
<td>Sep</td>
<td>8827</td>
<td>19 419</td>
</tr>
<tr>
<td>Oct</td>
<td>9658</td>
<td>19 316</td>
</tr>
<tr>
<td>Nov</td>
<td>96 61</td>
<td>18 356</td>
</tr>
<tr>
<td>Dec</td>
<td>64 152</td>
<td>12 8414</td>
</tr>
</tbody>
</table>

Table 5. Total amount of fuel in the boiler. Year 2007.

<table>
<thead>
<tr>
<th>Total in boiler</th>
<th>Bark (MWh)</th>
<th>Bark (ton)</th>
<th>Solid fuel (MWh)</th>
<th>Solid fuel (ton)</th>
<th>Solid fuel-Bark (MWh)</th>
<th>Solid Fuel-Bark (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>41 084</td>
<td>19 682</td>
<td>25 415</td>
<td>61 149</td>
<td>20 066</td>
<td>20 853</td>
</tr>
<tr>
<td></td>
<td>30 543</td>
<td>17 050</td>
<td>20 371</td>
<td>42 168</td>
<td>11 624</td>
<td>17 630</td>
</tr>
<tr>
<td></td>
<td>40 594</td>
<td>20 975</td>
<td>25 229</td>
<td>55 485</td>
<td>14 891</td>
<td>21 116</td>
</tr>
<tr>
<td></td>
<td>37 724</td>
<td>17 630</td>
<td>20 584</td>
<td>48 064</td>
<td>10 340</td>
<td>22 116</td>
</tr>
<tr>
<td></td>
<td>22 116</td>
<td>8 847</td>
<td>9 871</td>
<td>25 700</td>
<td>3 584</td>
<td>20 100</td>
</tr>
<tr>
<td></td>
<td>42 490</td>
<td>19 314</td>
<td>20 463</td>
<td>46 461</td>
<td>5 428</td>
<td>20 100</td>
</tr>
<tr>
<td></td>
<td>41 706</td>
<td>20 853</td>
<td>24 436</td>
<td>54 102</td>
<td>12 396</td>
<td>41 706</td>
</tr>
<tr>
<td></td>
<td>36 967</td>
<td>19 456</td>
<td>23 479</td>
<td>51 534</td>
<td>14 567</td>
<td>36 967</td>
</tr>
<tr>
<td></td>
<td>313 324</td>
<td>152 546</td>
<td>179 945</td>
<td>410 190</td>
<td>96 866</td>
<td>313 324</td>
</tr>
</tbody>
</table>
Table 6. Data from computer. Year 2007.

<table>
<thead>
<tr>
<th></th>
<th>Data from computer</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid fuel (ton)</td>
<td>Oil (kg)</td>
</tr>
<tr>
<td>Jan</td>
<td>26591</td>
<td>23265</td>
</tr>
<tr>
<td>Feb</td>
<td>20863</td>
<td>4894</td>
</tr>
<tr>
<td>Mar</td>
<td>27939</td>
<td>6291</td>
</tr>
<tr>
<td>Apr</td>
<td>19114</td>
<td>3405</td>
</tr>
<tr>
<td>Maj</td>
<td>11204</td>
<td>0</td>
</tr>
<tr>
<td>Sep</td>
<td>12894</td>
<td>12255</td>
</tr>
<tr>
<td>Okt</td>
<td>20802</td>
<td>57270</td>
</tr>
<tr>
<td>Nov</td>
<td>24436</td>
<td>4727</td>
</tr>
<tr>
<td>Dec</td>
<td>27756</td>
<td>11769</td>
</tr>
</tbody>
</table>

(Computer does not take oil production below 7 MW into account)

Total 191599 123876 (approx 150 m3)


<table>
<thead>
<tr>
<th></th>
<th>Production Johannes (MWh)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Network</td>
<td>FGC</td>
</tr>
<tr>
<td>Jan</td>
<td>46327</td>
<td>10238</td>
</tr>
<tr>
<td>Feb</td>
<td>41118</td>
<td>11441</td>
</tr>
<tr>
<td>Mar</td>
<td>42636</td>
<td>7680</td>
</tr>
<tr>
<td>Apr</td>
<td>30042</td>
<td>2352</td>
</tr>
<tr>
<td>May</td>
<td>15842</td>
<td>0</td>
</tr>
<tr>
<td>Sep</td>
<td>17621</td>
<td>186</td>
</tr>
<tr>
<td>Okt</td>
<td>33510</td>
<td>4612</td>
</tr>
<tr>
<td>Nov</td>
<td>43131</td>
<td>10056</td>
</tr>
<tr>
<td>Dec</td>
<td>50033</td>
<td>13044</td>
</tr>
</tbody>
</table>

Total 320260 59609 260651 97446

Table 8. Distribution of solid fuel in weight (%). Year 2007.

<table>
<thead>
<tr>
<th>Distribution solid fuel in weight-%</th>
<th>Bark</th>
<th>Waste wood</th>
<th>Dry chipped</th>
<th>Grot</th>
<th>Total ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moist (ton)</td>
<td>162426</td>
<td>26352</td>
<td>519</td>
<td>2303</td>
<td>191599</td>
</tr>
<tr>
<td>Moisture content %</td>
<td>55%</td>
<td>24%</td>
<td>21%</td>
<td>35%</td>
<td></td>
</tr>
<tr>
<td>Dry solid content %</td>
<td>45%</td>
<td>76%</td>
<td>79%</td>
<td>66%</td>
<td></td>
</tr>
<tr>
<td>Share</td>
<td>76.7%</td>
<td>21.2%</td>
<td>0.4%</td>
<td>1.6%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Dry (ton)*</td>
<td>72604</td>
<td>20080</td>
<td>408</td>
<td>1508</td>
<td>94600</td>
</tr>
</tbody>
</table>

* accounted for in dry weight (ton)


<table>
<thead>
<tr>
<th>Facility</th>
<th>Johannes</th>
<th>Ersbo</th>
<th>Carlsborg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil consumption (m³)</td>
<td>248</td>
<td>255</td>
<td>33</td>
</tr>
</tbody>
</table>
2. Gästrike Återvinnare

The data concerning amount of waste collected in the municipalities of Gävle, Sandviken, Hofors, Ockelbo and Älvkarleby are shown in tables 10 and 11.

Table 10. Amount of household waste collected by Gästrike Återvinnare in 2007 (tones)

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gävle</td>
<td>1310</td>
<td>1109</td>
<td>1611</td>
<td>1625</td>
<td>1722</td>
<td>1568</td>
<td>1627</td>
<td>1727</td>
<td>2033</td>
<td>2255</td>
<td>1559</td>
<td>1540</td>
<td>19686</td>
</tr>
<tr>
<td>Sandviken</td>
<td>1002</td>
<td>801</td>
<td>495</td>
<td>381</td>
<td>398</td>
<td>365</td>
<td>412</td>
<td>480</td>
<td>0</td>
<td>0</td>
<td>327</td>
<td>287</td>
<td>4948</td>
</tr>
<tr>
<td>Hofors</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>11</td>
<td>30</td>
<td>40</td>
<td>47</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>38</td>
<td>45</td>
<td>219</td>
</tr>
<tr>
<td>Ockelbo</td>
<td>75</td>
<td>59</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>144</td>
</tr>
<tr>
<td>Älvkarleby</td>
<td>148</td>
<td>115</td>
<td>127</td>
<td>141</td>
<td>137</td>
<td>135</td>
<td>177</td>
<td>143</td>
<td>0</td>
<td>0</td>
<td>135</td>
<td>140</td>
<td>1398</td>
</tr>
<tr>
<td>Wet waste</td>
<td>69</td>
<td>58</td>
<td>69</td>
<td>56</td>
<td>86</td>
<td>74</td>
<td>89</td>
<td>117</td>
<td>59</td>
<td>83</td>
<td>73</td>
<td>67</td>
<td>900</td>
</tr>
<tr>
<td>Compost</td>
<td>581</td>
<td>512</td>
<td>573</td>
<td>566</td>
<td>627</td>
<td>589</td>
<td>549</td>
<td>581</td>
<td>596</td>
<td>757</td>
<td>737</td>
<td>779</td>
<td>7447</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3185</td>
<td>2654</td>
<td>2893</td>
<td>2769</td>
<td>2981</td>
<td>2869</td>
<td>3095</td>
<td>2688</td>
<td>3095</td>
<td>2869</td>
<td>2858</td>
<td>2858</td>
<td>34742</td>
</tr>
<tr>
<td>Combustible waste</td>
<td>2604</td>
<td>2141</td>
<td>2321</td>
<td>2203</td>
<td>2353</td>
<td>2172</td>
<td>2346</td>
<td>2513</td>
<td>2092</td>
<td>2338</td>
<td>2133</td>
<td>2078</td>
<td>27294</td>
</tr>
</tbody>
</table>

Table 11. Wood and combustible waste collected by Gästrike Återvinnare in 2007 (kg)

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>136160</td>
<td>104380</td>
<td>248220</td>
<td>393580</td>
<td>422080</td>
<td>420180</td>
<td>683020</td>
<td>538700</td>
<td>417160</td>
<td>474720</td>
<td>245480</td>
<td>630580</td>
<td>4714260</td>
</tr>
<tr>
<td>Comb. waste</td>
<td>337640</td>
<td>247700</td>
<td>446500</td>
<td>551280</td>
<td>559370</td>
<td>516660</td>
<td>735280</td>
<td>630000</td>
<td>582240</td>
<td>651200</td>
<td>477800</td>
<td>287700</td>
<td>6023370</td>
</tr>
<tr>
<td>Additional amount of waste collected ( destined to incineration)</td>
<td>3662360</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In table 12 the amounts of waste collected from 2003 to 2007 are shown:

Table 12. Amounts of waste collected from 2003 to 2007 (tones)

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of waste collected</td>
<td>35288.2</td>
<td>36743.6</td>
<td>35804.3</td>
<td>35655.6</td>
<td>34742</td>
</tr>
</tbody>
</table>

The price the company pays to Sundsvall Energi to get rid of the waste is 686 kr/ton. Of this price, the waste incineration tax corresponds to 99 kr/ton, and 200 kr/ton to the total transportation cost. In the transportation cost other costs are included, as the reloading cost. Taking into account these additional costs, the approximate transportation cost is of about 160 kr/ton.
3. Sundsvall Energi

The answers to some of the questions are:

Fly Ash content to landfill: 2 % wet-tons of the waste. The flyash is wet because we have wet cleaning steps of the fumes.
Then we have approx. 15 % slag (around 12.5 % water of the slag) which we sort to recycle metals (7 %) and constructions material (the rest).

Industrial waste: We treat only non branchespecific waste (wood, paper, plastic etc) from more or less all companies in the area. The waste is dryer and has a little higher heating value.

Transportation cost varies a lot, but my suggestion is 0.8 SEK/km,ton. No special transportation needs.

4. Falu Energi & Vatten

In the municipality of Falun the household waste is collected by the company Falu Energi & Vatten. The amount of waste collected the year 2007 was the following:

<table>
<thead>
<tr>
<th>Amount of waste in ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustible waste</td>
</tr>
<tr>
<td>Compostable waste</td>
</tr>
<tr>
<td>Waste to landfill</td>
</tr>
<tr>
<td>Bulky waste</td>
</tr>
<tr>
<td>Packaging and paper</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
</tbody>
</table>

The combustible waste collected in Falun is transported to Bäckelund incinerator in Borlänge. Part of the bulky waste is also incinerated, while the remaining fraction is destined to recycling and landfill disposal.
5. Tierps Kommun

In the municipality of Tierp the household waste is collected by Tierps Kommun. The amount of household waste collected in 2007 was 4000 ton. The amount of waste wood collected was 2750 ton. The combustible waste is transported to Uppsala for incineration.

Price to incinerate the waste:

- Price of the waste 475 sek./ton
- Incineration tax 355sek./ton
- Transportation cost 74sek./ton

6. Uppsala Kommun

The answer from Uppsala Kommun was:

HOUSEHOLD WASTE IN UPPSALA, DATA FROM YEAR 2007

The government has decided that every company that manufactures, imports, fills or sells packaging or packaged goods shall be responsible for there being a collection system where end customers can deposit packaging for recycling. The same applies to newspapers and recycling.

The producers have set up recycling stations at 45 locations in Uppsala. This is where you should go to discard newspapers as well as plastic, paper, metal and glass packaging. There are also often containers for newspapers, batteries and clothing.

The municipality Uppsala has set up 8 recycling centres where you can discard coarse waste which can be such things as old furniture, household machines, bicycles or waste from normal gardening. There are also 16 environmental stations were you can leave your hazardous waste.

The owners of the properties have to classify and sort the Household waste in the following fractions:

- HAZARDOUS WASTE
- HARD PLASTIC PACKAGES
- SOFT PLASTIC PACKAGING
- PAPER PACKAGING
- NEWSPAPERS AND PRINTED MATTER
- METAL PACKAGING
- ELECTRICAL AND ELECTRONIC PRODUCTS
- BIOLOGICAL

It’s not allowed to discard any of the fractions mentioned above to the COMBUSTIBLE fraction.

<table>
<thead>
<tr>
<th>Collected household waste (tonnes) in the year of 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustible</td>
</tr>
<tr>
<td>Biological</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

- Collected waste wood 5672 tonnes
- The transportation price depends on the size of the vessel (130 – 660 litres) and the walking distance when collecting the vessel. Anyway it’s between 12.55 and 80.74 Swedish crown each collecting time
- We have to pay 750 Swedish crown per tonnes to incinerate the waste (150 incineration tax)

7. Vattenfall Värme Uppsala

The answers from Vattenfall Värme Uppsala were:

Heating value: about 2.5 to 3.2 MWh per ton waste fuel.
We are treating about 360 kton waste fuel (household and industrial waste) per year.
Most of the waste fuel are delivered from communities and industries in the region of Uppsala and Stockholm.

Prices: Because we are acting at a market in competition I can’t unveil our prices.
8. Stora Enso

The answers from Stora Enso concerning Skutskär pulp mill were:

Quantity of sub-products: bark, 200000 wet tons/year
Physical characteristics of the sub-products:

- Calorific values 19.5 KJ/kg (dry solid)
- Moisture 55-60 %
- Density
- Ash quantity 5 % (dry sample)

Production will be pretty much the same in the future years, although they might burn more fuel in their own boiler.

Prices are not revealed for competitive reasons.

9. SITA Sverige AB

SITA is a company which collects waste in the North part of Gävle, and in the surroundings north of Gävle. The company collects different types of waste:
- Household waste
- Industrial waste
- “Slam”

The industrial waste is mainly collected from big industries, which are Sandvik (around 40%), Korsnäs (around 25%) and Stora Enso (around 10%). The rest is collected from smaller industries.

The waste collected can be divided in four fractions:
- Wood
- Combustible waste
- Paper
- Construction materials (“Fyllnadsmassor”): Brick (“tegel”) etc.

Wood and combustible waste are destined to incineration. About 80% of these fractions go to Sundsvall incineration plant, and the remaining 20% goes to Uppsala incineration plant.
The amount of waste collected in 2007 was the following:
- Household waste: 26780 ton
- Industry waste: 24183 ton
- Wood waste: 9599 ton
These amounts correspond to the waste that goes to incineration.

The heating value of the waste that goes to incineration is about 2.5-3 MWh/ton.

10. Bollnäs Energi

The answers from Bollnäs Energi were:

- What is done with the waste nowadays? What is done with the combustible fraction of the waste nowadays? Which are the incinerators that burn the combustible waste?
  Nowadays the waste from Bollnäs, Ovanäker, Söderhamn, Ljusdal and Häradalens communities is incinerated in Säverstaverket in Bollnäs. Säverstaverket have permission to incinerate 40,000 tonnes municipal waste and industrial waste per year. Also 25,000 tonnes of wood which has been painted or similar treatment (is that demolition wood?) are permitted to incinerate.
- How much waste is collected per year? In which municipalities?
  In Bollnäs and Ovanäker is about 10,000 tonnes waste collected per year.
- What is the average heating value of the combustible waste?
  For municipal waste the average heating value is about 2.7 MWh/tonne, and for industrial waste it is about 3.0 – 3.2 MWh/tonne.
- How much waste is collected per year from industries? From which industries?
  I can only answer for the plant Säverstaverket. It is about 15,000 tonnes industrial waste which is incinerated per year. Mostly collected in Bollnäs, Ovanäker and Söderhamn
* Price of the waste. Supplier of waste to Säverstaverket has to pay 730 SEK/tonne. That includes tax for 450 SEK/tonne.
11. Sydved

The answers from Sydved were:

- Which quantities of sub-products useful for combustion (bark, wood waste…) are produced? (amount/year)
  
  We (in this text “we” refers to StoraEnso Bioenergi AB) handle bark and sawdust from Skutskär.
  
  Bark, about 550 000 m³s or 380 000 MWh.
  
  Sawdust 105 000 m³s or 65 000 MWh.

- What are the physical characteristics of the sub-products?
  
  * Calorific value  Roughly it is 19,7 MJ/kg for bark and 19,2 for sawdust
  
  * Moisture  55 % for bark and about the same for the sawdust
  
  * Density  No reliable numbers at the moment.
  
  * Ash quantity  3 % for bark and 0,7- 1% for sawdust

- What is the price of these fuels?
  
  * Cost of the fuel (kr/ton) or (kr/MWh).
    
    Sorry but I am not allowed to give this information as we are re-negotiating the prices right now.
  
  * Cost of transportation of the fuel (kr/ton·km) or (kr/MWh·km)
    
    Return loads play an important role in the price, but in general it is cheaper than transporting chipped material from the forest.

- Where are the fuels transported?
  
  Mainly Fortum Brista (Märsta) and Gävle värmeverk.

- What will be the production in the next years be like? Is it going to increase, decrease, maintain the same level?
  
  We will handle about 70 000 m³s less bark next year which goes into Skutskärs own heating.
Appendix 3: Johannes CHP power plant

Gävle Energi’s main combustion facility is the Johannes CHP plant, which is located in Johannesbergsvägen, in the south of Gävle. The plant is in operation from September to May. In Johannes plant the fuels are woody biomass resources, consisting mainly of bark, forest residues and waste wood. However, when the plant has to be started oil is used as fuel. When there are technical problems which cannot be resolved with the usage of the usual fuels, oil is also used.

The basic scheme of the power plant is shown in Fig. 1, and in Fig. 2 a view of the plant can be seen.

![Diagram of Johannes power plant](image)

<table>
<thead>
<tr>
<th>1. Storage of biofuel</th>
<th>6. Flue gas condenser</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Mixing of biofuel</td>
<td>7. Chimney stack</td>
</tr>
<tr>
<td>3. Transportation of</td>
<td>8. Turbine</td>
</tr>
<tr>
<td>biofuel to the boiler</td>
<td>9. Heat accumulators</td>
</tr>
<tr>
<td>4. Boiler</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Scheme of Johannes power plant
The biofuels are stored in piles at the outside of the plant, separated by their origin and properties. When the fuel is going to be supplied to the boiler, first it is mixed and moved to the silo by screw conveyors. The mixture is done in an approximate manner, and then the fuel is transported by a conveyor belt to the boiler.

The fuel is burned in a bubble fluidised bed boiler, shown in Fig. 3.
The high-pressure steam produced in the boiler goes to a backpressure turbine, where it expands and cools, producing electricity. The steam is then used in the district heating network. The energy content of the steam is defined by its pressure, and by changing that pressure it is possible to control the heat-to-power ratio. The higher the steam pressure, the more is the electricity production decreased, and the heat production increased. The exhaust steam is condensed in two condensers, where the heat from the steam is extracted by water, that after goes to the hot water supply pipe of the district heating network.

The basic scheme of the cycle is shown in Fig. 4.

![Fig. 4. Scheme of the thermodynamic cycle in Johannes power plant (http://www.chp-info.org/index.html)](http://www.chp-info.org/index.html)

The exhaust gases exit the boiler and go through an electrostatic precipitator, where the particulate matter is eliminated with very high efficiency. Then the clean gases go through a flue-gas condensation system, where the heat from the exhaust gases is extracted, and used in the district heating network.

The plant has also two heat accumulators, which are used to store the hot water when it is not necessary, so that it can be used afterwards, when the demand is higher. In other words, the accumulators compensate for the daily load variations in the heat demand.

The mixture of sand-ashes is recycled, so that the majority of the sand can be reutilized in the boiler. The ashes are collected and stored for further disposal.
In summary, the technical characteristics of Johannes plant are the following (data for year 2007):

- Start up year: 1999
- Boiler/furnace: Bubble Fluidized Bed (BFB) boiler
- Boiler capacity: 77 MW
- Flue gas condensation unit in two stages: 22 MW

<table>
<thead>
<tr>
<th>Fuel</th>
<th>MWh</th>
<th>Energy (%)</th>
<th>Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bark</td>
<td>184910</td>
<td>76.4</td>
<td>84.8</td>
</tr>
<tr>
<td>Wood waste</td>
<td>88328</td>
<td>21.5</td>
<td>13.8</td>
</tr>
<tr>
<td>Forest residues</td>
<td>6834</td>
<td>1.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Dry chipped</td>
<td>1705</td>
<td>0.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

| Oil (m³) | Johannes: 248 m³ | Ersbo: 255 m³ | Carlsborg: 33 m³ |

- Fuel input: it varies considerably depending on the month.

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>84.04</td>
<td>70.93</td>
<td>79.19</td>
<td>69.03</td>
<td>46.79</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>61.23</td>
<td>75.80</td>
<td>80.33</td>
<td>80.44</td>
</tr>
</tbody>
</table>

**Fuel input for year 2007**
- Electrical efficiency, defined as \(\frac{\text{net power output}}{\text{fuel input}}\): 28.5%

- Total efficiency, defined as \(\frac{\text{net power output} + \text{district heating output}}{\text{fuel input}}\): 128%

- Steam pressure: 94 bar
- Steam temperature: 480 °C
- Steam flow: 29 kg/s
- Operation hours: 5520 hours/year
- Emissions: average data for year 2007

<table>
<thead>
<tr>
<th>Emission</th>
<th>NO(_x) (mg/MJ)</th>
<th>NH(_3) (mg/MJ)</th>
<th>Sulphur (mg/MJ)</th>
<th>Dust (mg/Nm(^3))</th>
<th>CO (mg/MJ)</th>
<th>N(_2)O (mg/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow in tonnes</td>
<td>76.63</td>
<td>1.84</td>
<td>0.5</td>
<td>7</td>
<td>97.7</td>
<td>3.65</td>
</tr>
</tbody>
</table>
Appendix 4: Calculation of the transportation cost

For the calculation of the price of transportation of the fuels, different sources have been used.

According to Gästrike Återvinnare, the total transportation cost of the waste from Forsbacka to Korstaverket incineration plant is about 200 kr/ton. There are other costs included in the total transportation cost, like the reloading cost. An approximate value for only the transportation cost would be 160 kr/ton. The approximate distance from Gävle to Sundsvall is 214 km. If we want to define the cost per ton and km:

\[
\frac{160 \text{ kr}}{214 \text{ km}} = 0.75 \frac{\text{kr}}{\text{ton} \cdot \text{km}}
\]

Therefore, an approximate transportation cost for the waste would be 0,75 \( \frac{\text{kr}}{\text{ton} \cdot \text{km}} \). This value corresponds with the approximate value of 0,8 \( \frac{\text{kr}}{\text{ton} \cdot \text{km}} \) obtained from Sundsvall Energi sources.

The other used source is Gävle Energi. The transport of one chipped wood waste (130 m\(^3\)) has the cost of:
- Load + unload: 400 kr
- Transport: 200 kr (each transport is about 10 km of distance)

Focusing only in the transportation cost:

\[
\frac{200 \text{ kr}}{10 \text{ km}} = 20 \frac{\text{kr}}{\text{km} \cdot 130 \text{ m}^3} \cdot \frac{\text{m}^3}{200 \text{ kg}} \cdot \frac{10^3 \text{ kg}}{\text{ton}} = 0.77 \frac{\text{kr}}{\text{ton}}
\]

The obtained value approximates very well with the other two values. Therefore, it can be concluded that an approximate transportation cost for the fuels would be:

\[
\frac{\text{kr}}{\text{ton} \cdot \text{km}} \quad \text{Transportation Cost: 0.75 - 0.8}
\]
However, not all the fuels have the same heating value per ton, and the interesting value to compare is the price per MWh. Therefore, with the heating values of the different fuels, a price of transportation in kr/MWh·km can be calculated. For the calculation, the average value of $0.77 \frac{kr}{ton \cdot km}$ is taken. The obtained values are shown in Table 13:

Table 13. Calculated transportation cost for the biofuels of study

<table>
<thead>
<tr>
<th>FUEL</th>
<th>Bark</th>
<th>Forest residues</th>
<th>Wood waste</th>
<th>Pellets</th>
<th>Briquettes</th>
<th>Waste</th>
<th>Peat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net calorific value as received (MWh/ton)</td>
<td>1.38-2.50</td>
<td>1.67-2.50</td>
<td>3.3-4.4</td>
<td>4.67</td>
<td>4.81</td>
<td>2.9</td>
<td>2.78-3.33</td>
</tr>
<tr>
<td>Transportation cost (kr/MWh·km)</td>
<td>0.31-0.56</td>
<td>0.31-0.46</td>
<td>0.17-0.23</td>
<td>0.16</td>
<td>0.16</td>
<td>0.26</td>
<td>0.23-0.28</td>
</tr>
</tbody>
</table>

Another source of information for the transportation cost of biofuels is Eubionet 2. In a study of the “Supply chain for wood chips from early thinning” in central Sweden (Factsheet 7), near the town of Falun, some of the results obtained were the following:

| Road transport-container truck (10 km) | 17 |
| Road transport-container truck (100 km) | 40 |

From these data, a cost of transportation can be calculated. The result is:

- For 10 km: $1.7 \frac{kr}{MWh \cdot km}$
- For 100 km: $0.4 \frac{kr}{MWh \cdot km}$

Therefore, the cost of transportation varies between these two values. For 100 km, the value corresponds with the values calculated before. However, for 10 km, the cost increases, which means that the transportation costs calculated for each of the fuels may change depending on the distance of transportation, and should not be considered as exact values.