

Small-scale CHP from biomass – *environmental, techno- and socioeconomic aspects*

*Based on results from a demonstration project in Southeast
Sweden*



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1 Foreword

This report includes techno-economic and socio-economic as well as an LCA assessment of three small scale CHP technologies within the Life+ *project Small Scale CHP from biomass – a demonstration in Southeast Sweden (2014-2020)*, which has been financed within the EU Life+ programme and partly by the Swedish Energy Agency and Swedenergy. The purpose of the study is to give an economic perspective on small scale CHP installations, both from a technical perspective with payback times and from a socioeconomic perspective including possible additional working hours during different phases of an installation and running the technologies. The data for the analysis in this report is based on the experience from three different demonstrations plants: a gasifier in Hultsfred, a Wet Steam Turbine in Ronneby and an Organic Rankine Cycle in BräkneHoby.

The goal for the demonstration project Small Scale CHP from biomass has been to disseminate experience and knowledge to pave the way for others to invest in small scale CHP technologies.

The authors of the study will give a large thanks to all involved in the work with the demonstration project and especially to the members of the steering group from Svebio, Energiföretagen Sverige, LNU and VEAB.

The study has been possible due to financial support from the EU Life+ programme, the Swedish Energy Agency and Swedenergy.

2 Summary

This study has been conducted by Energikontor Sydost (Energy Agency for southeast Sweden) as a result from a demonstration project running from June 2014 until December 2020. In this report the aim has been to evaluate the economic and socio-economic aspects of three technologies for small scale cogeneration. The three technologies are:

- A 49 kW_e Organic Rankine Cycle (ORC) unit at district heating plant in BräkneHoby, Sweden
- A 500kW_e Wet Steam Turbine (WST) at a district heating plant in Ronneby, Sweden
- A 40 kW_e gasifier at dairy in Hultsfred, Sweden

The aim has also been to evaluate the environmental impact of the three technologies, by conducting a Life cycle analysis (LCA).

Europe and Sweden are in the middle of the transition from fossil and nuclear-based electricity to renewable energy resources such as wind, solar and bioenergy. The increasing share of weather dependent electricity (solar, wind power) increases the need for planned electricity production that can guarantee production all year round, such as hydropower and cogeneration from biomass, in combination with energy storage for solar and wind in the future.

Cogeneration, also called combined heat and power, is resource efficient and independent of weather conditions and can supply electricity when needed most – during the winter when it is dark and cold.

For combined heat and power (CHP) plants, to operate in a way that is economically and ecologically beneficial, both the electricity and the heat produced must be utilized. Therefore, all cogeneration is based on the existence of a district heating network or an industry that can receive the heat generated in the process. The district heating industry is an important target group for small scale CHP because the heating base already exists. The sawmill industry is also pointed out as an important industry where small-scale co-generation has great potential.

This study shows that small scale CHP technologies is available with a reasonable payback time. For the conditions given in this study the base-case for the gasifier gives the shortest payback time. However, the payback time is shown to highly depend on following aspects:

- Operating hours
- Price of electricity
- Possible tax relief
- Price of biomass
- Discount rate

The CO₂ emissions saved by a small-scale CHP unit based on biomass will depend on the generation of electricity saved. The saved CO₂ emissions will increase if fossil fuels are replaced because of the installation. The largest emissions will be saved if the electricity replaces electricity produced from coal power plants.

If small-scale CHP is installed at local district heating plants, local heating plants, industries or other businesses (e.g agriculture), it can increase the planned electricity production at the

same time as the safety-of-supply of these actors increases in case of power outage or emergencies.

This report shows that the advantages of bioenergy lie in an already well-developed infrastructure and that it is a local raw material. The system for extraction of branches and tops and wood chips already exists, but the market will expand with an increased demand. A small-scale CHP unit will contribute to establishment of local jobs during construction and installation of the technology. But since the suppliers of the technology and the raw material is located within EU, an increase of CHP units will create jobs within EU. That will both contribute to the economy but also to the security of supply of energy in the EU.

Locally produced heat and electricity also promote the countryside because it is possible to use local raw materials.

3 Aim, Scope, delimitations

This chapter presents the aim and scope of the analysis.

3.1 Aim

The overall aim of this report and study has been to evaluate the economics and environmental aspects for three different small-scale CHP technologies and to analyse the impact on three demonstration plants as well as the potential for small scale CHP in the region of south east Sweden.

The goal of this report can be divided into four sub-goals:

1. To evaluate the economics, both from a techno-economic perspective and a socio-economic perspective
2. To evaluate the environmental aspects of three small scale CHP technologies by a Life cycle assessment.
3. To map new CHP installations based on the three demonstration plants in the project
4. To analyse the potential for small-scale CHP technologies in south east Sweden

The aspects included in the socioeconomic and environmental evaluation in this report is described in Table 1.

Table 1 Socio-economic and Environmental analysis

The socio economic and environmental analysis will include:	
1.	Economic analysis for each technology and comparison
2.	LCA analysis for each technology
3.	Socio-economic analysis for each technology will focus on south east Sweden including:
	a) New jobs (direct and indirect)
	b) Security of supply
	c) Impact on local economy (circular economy) by evaluate the importance of local/regional small-scale CHP facilities in the system
	d) Health and safety
4.	Mapping of new small-scale CHP built during the project period
5.	Evaluate the potential for small scale CHP – with focus on south east Sweden

Five of the global goals for sustainable development are considered in this report and in the long run in every installation of a small scale-CHP based on biomass. The five goals considered are found in Figure 1.



Figure 1. Goal 7,8,9,11 and 13 are the goals of the 17 global goals that will be considered when installing a small-scale CHP unit in Sweden or elsewhere in EU.

The long-term goal for the demonstration project has been to increase the number of employees regionally, nationally and in the future also in EU.

3.2 Delimitations and key assumptions

The study is based on the demonstration of three pilot plants within the Life+ project *Small scale combined heat and power based on biomass in the region of south east Sweden*.

The evaluated technologies are:

- An 49kW_e Organic Rankine Cycle (ORC) unit at district heating plant in BräkneHoby, Sweden
- A 500kW_e Wet Steam Turbine (WST) at a district heating plant in Ronneby, Sweden
- A 40 kW_e gasifier at dairy in Hultsfred, Sweden

The input data is based on the experience from running the plants.

The evaluation of the potential for small scale CHP is limited to the area of south east Sweden, but a discussion is included on the potential on EU-level.

3.3 Abbreviations

CHP – Combined heat and power

ORC- Organic Rankine Cycle

Svebio – Swedish biomass association

WST- Wet Steam Turbine

GWP – Global warming potential

LCA – Life cycle assessment

Odt – Oven dried tonne

GHG – Greenhouse gas emissions

SRC – Short rotation crops

4 Introduction

Europe and Sweden are in the middle of the transition from fossil and nuclear-based electricity to renewable energy resources such as wind, solar and bioenergy. The increasing share of weather dependent electricity (solar, wind power) increases the need for planned electricity production that can guarantee production all year round, such as hydropower and cogeneration from biomass, in combination with energy storage for solar and wind in the future.

To achieve our environmental goals many different **initiatives** are needed in all areas. Cogeneration is very resource efficient and has an efficiency of 90-100 %, and even above 100 % if the lower heating value is used. About 30-40 % can be electricity and the rest are heat. For small-scale CHP plants, electricity efficiency is between 2 to 20 %.

In addition, cogeneration is independent of weather and can supply electricity when needed most – during the winter when it is dark and cold. However, all cogeneration is based on the existence of a district heating network or an industry that can receive the heat generated in the process.

The target group for small scale cogeneration, also called combined heat and power is therefore industries or business with a heating demand or district heating or local heating plants without electricity generation.

Combined Heat and Power (CHP) technologies based on biomass combustion have great potential to reduce CO₂ emissions since they use renewable energy sources, such as wood fuels or sawdust. Typical fields of application for biomass CHP plants are wood processing industries, sawmills, district heating systems and industries with a high process heating and cooling demand. For CHP plants to operate in a way that is economically and ecologically beneficial, both the electricity and the heat produced must be utilized.

CHP technologies is already available on both Swedish and European markets. But, due to the high installation costs, and a lack of information about its efficiency, all technologies are currently not widely used in small-scale implementations (less than 10 MW_{thermal}). Extensive research has been undertaken to illustrate the vast environmental potential of CHP technology but a larger initiative that demonstrate the technologies in different applications was missing.

Therefore, to meet the gap between commercialization and research, three different techniques for small-scale electricity production of biomass-based cogeneration have been built and demonstrated between 2014 and 2020 in southeast Sweden as part of the project *LIFE + Small Scale CHP*. Partners of the project, where the demonstration plants are built, are Emå Dairy in Hultsfred and Ronneby Miljö & Teknik AB and Ronneby Miljöteknik Energi AB in Ronneby. The project is also partly financed by the Swedish Energy Agency and Swedenergy.

During 2014 until 2020 three demonstration of prototypes for small scale CHP based on biomass have been procured, build, and demonstrated presenting three different technology solutions. The three technologies are:

- An Organic Rankine Cycle (ORC) unit at district heating plant in BräkneHoby, Sweden
- A Wet Steam Turbine (WST) at a district heating plant in Ronneby, Sweden
- A gasifier at dairy in Hultsfred, Sweden

The technical experience and the lessons learned from the investment has been gathered in three reports, one for each technology¹.

4.1 *Status of small-scale CHP in the beginning of the 2010s*

This Chapter describes the status of each small-scale CHP technology considered in this report in the beginning of the project in 2014.

4.1.1 ORC

In the beginning of 2010s, the ORC technology, in larger scales, could be considered commercial in parts of Europe, but not in the small scale and not in Sweden. The break-through for the ORC technology in Europe is a consequence of policies that provided incentives to use the technology. Turboden was at that time the largest supplier of ORC facilities, with 16 standardized plants in sizes from 587 kW to 2.9 MW electricity. The main application for ORC technology is found in industries and heating plants with heat sources around 100°C, but can also be used in combination with smaller pellet boilers in buildings, such as hotels, shopping malls, greenhouses, etc.

Existing ORC facilities in Sweden in the beginning of the 2010s

There were three ORC facilities from Opcon, of which one was in operation. The one in operation had a capacity of 2.3 MWe and was connected to a biomass boiler in Falköping. Two Swedish suppliers of ORC technologies was founded in the beginning of 2010s. The company Clemon delivered its first ORC to SSAB in 2015. The company Againty had a small testing plant back in 2012.

Existing ORC facilities in Europe in the beginning of the 2010s

The company Turboden had over 175 installations (up to 2015) in Europe, mainly in Italy, Austria and Germany. Clemon was new on the market in the beginning of the 2010s and had up to (2015) delivered 16 ORC units to England. The company Exergy in Italy have three ORC facilities between 0.3 – 1 MWe which uses biomass. The biggest player on the world market was the American company ORMAT.

4.1.2 Wet Steam Turbine

Wet Steam Turbines have been around for a long time and have been tested in several different areas of use. It has previously been used in marine applications. Since 1995, large groups have acquired many smaller turbine manufacturers in Europe and the United States. The interest in smaller turbines has thus disappeared and the development have stopped. In the beginning of the 2010s there were only some companies that continued the development of Wet Steam Turbines.

Existing Wet Steam Turbines in Sweden in the beginning of the 2010s

The Swedish company, Svenska foder, had a Wet Steam Turbine called Powerbox, with installed capacity of 0.5 MW from the company Opcon. In 2016, the energy company E.ON was to start a Powerbox, 820kW, at a district heating plant.

¹ The reports are available at the project homepage: <http://energikontorsydost.se/smallscaleCHPLife>

Existing Wet Steam Turbines in Sweden in the beginning of the 2010s

The company M+M had delivered a Wet Steam Turbine, with 500 kW capacity, to a company in Italy. Other companies on the market was KK&K, part of Siemens.

4.1.3 Gasifiers

Gasification of biomass at both small and large scale is a technology that has been between research and commercialization for a long time (Ekbom et al. 2014). Therefore, when this project started in 2014, the factual basis of the operating experience from a gasifier was small. The lack of knowledge and high costs for gasification were confirmed in the literature (Nohlgren et al. 2014).

Government subsidies, mainly in Germany and England, have benefit small scale gasification plants with a fuel capacity less than 1 MW. It is in these size the commercial gasification plants are available. The technology used in these plants is co-current gasification. The advantage of that technology is that almost all the tar is burned, the technology is relatively simple, tested and has relatively low costs. Several facilities have shown long operating times. The disadvantages are that the technology is limited in size (up to about 2 MW or 10 tonnes/day of added fuel (E4Tech, 2009)), the temperature from the gasifier, and the need of dry biomass. Another disadvantage that lately has become a potential source of income is the relatively high proportion of coke that does not convert. The latter has been shown to be classified as biochar².

There are also gasifiers with other technology, but these are still not completely commercial. An example of a gasification plant with a fluidized bed is Repotec's plant in Güssing, Austria, which was built in 2002 and has had many operating hours. Gobigas gasifier in Gothenburg, Sweden, was also built by Repotec (in 2013). Both facilities have functioned well technically but are both closed for economic and political reasons.

The development of micro-gasifier got its break-through in the beginning of 2010s, especially in southern Germany and northern Italy, much depending on the generous input tariffs prevailing in these countries at that time. The gasification plants are mainly used in properties, such as hotels, apartment buildings and agriculture.

Existing small-scale gasification facilities in Sweden in the beginning of the 2010s

Before the Life+ project Small scale CHP started, there was none small-scale gasification plan for electricity production in Sweden. The pulp mill Södra Cell in Värö had, however, previously a gasifier where the gas was used directly in their process.

Existing gasification facilities in Europe in the beginning of the 2010s

Small-scale gasifiers were already commercially available in Europe in the beginning of the 2010s. At that time, it was mainly two suppliers on the market. The main actor was the company Spanner Re2 which had delivered (up to 2015) about one hundred gasifiers in the size of 30-45 kW electricity. The other company on the market at that time (up to 2015), the Finnish company Volter, had a large market share in Finland and in the United Kingdom. However, most gasifiers were installed in Germany followed by Italy. One or a few facilities were installed in Latvia, Slovenia, Finland, Poland, Great Britain, Australia, Slovakia, Hungary, and Great Britain.

² Biochar is a product from biomass that has been carbonized (by pyrolysis, gasification or torrefaction) to varying degrees. Biochar can be used as soil improvement in plant beds and/or buried to reduce carbon dioxide emissions into the atmosphere.

4.2 Future small-scale CHP is based on sustainable biomass

Bioenergy is the energy generation from plant-based raw materials, so-called biomass. Biomass can be both crops and forest products. Bioenergy is largely based on residual products and by-products from forestry (Forest research 2014), agriculture, forestry and the food industry.

Bioenergy from agriculture consists mainly of cultivated energy crops, but sometimes straw and other residues are also used. Sugar cane, corn, wheat, and rapeseed are used for fuel production.

When it comes to biomass for small scale CHP applications, focus is on bioenergy based on forest residuals and by-products.

The Swedish forest is mainly used for timber production (45 %), which becomes furniture, building timber and other wood products, and pulpwood (40-45 %) which becomes newspaper, packaging, other paper products and textiles. The manufacturing of timber and pulp generates woody by-products, which entails that more than 10 % of the harvested wood ends up as bioenergy.

Figure 2 shows how different parts of a tree go to different areas of use. The parts of the tree that cannot be further processed or refined are converted into bioenergy. Branches and tops that become residues during felling remain in the forest or go to district heating plant and converts to heat and power. By-products such as bark, sawdust, dry chips, etc. from the sawmill industry converts to heat and power in district heating plants. The pulp and paper industry and the sawmill industry use a large part of the biomass from logs, such as shavings, wood waste and bark, for energy supply in the production of pulp and wood materials. Residuals from the manufacturing industry (i.e. floor production) and the bio-based part of our house waste is also converted into bioenergy (Black-Samuelsson S et. Al 2017).

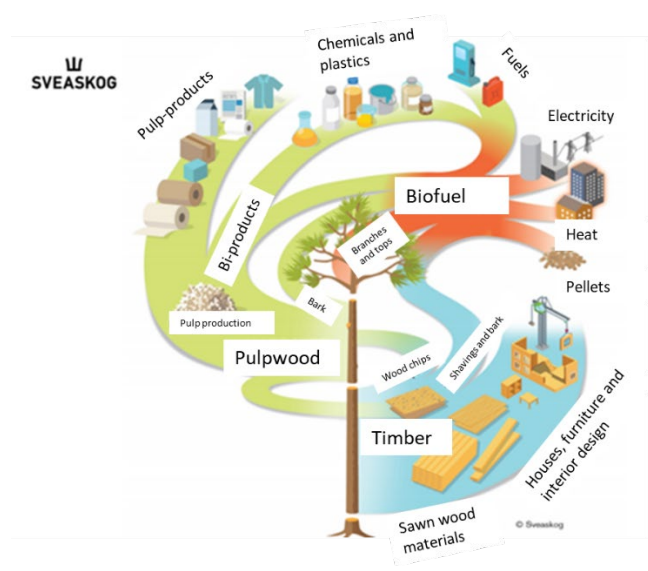


Figure 2. Illustration of how the different parts of the tree are used for different purposes. The parts of the tree that cannot be further processed are used as biofuel. In Sweden, only residual products are used for biofuel production. Picture: Sveaskog 2018, and translated by Energikontor Sydost.

In a global perspective, agriculture, forestry, and other land use causes about 25 % of global greenhouse gas emissions. To combat the climate effect, deforestation must be reduced and

instead replanting, and restoration of depleted forests are needed to increase carbon dioxide stocks in a global perspective (NEP 2017). Following the UN Climate Conference in Paris in 2015, almost all countries have signed the Climate Convention and the Paris Agreement, which means that ecosystems' carbon dioxide stocks and sinks must be preserved and promoted.

However, deforestation is not a problem in EU, Sweden or in south-eastern part of Sweden (which is focus in this project). In Sweden, timber stocks and the coal stocks have increased over the past 100 years. An increase in timber and coal stocks has also taken place in Europe's forest-rich countries (Forest Europa 2015).

The climate advantage of bioenergy is based on the fact that biomass is continuously newly formed. Sustainably produced bioenergy is part of the carbon dioxide chain and does not contribute to net emissions of carbon dioxide, unlike the combustion of fossil fuels (Figure 3).

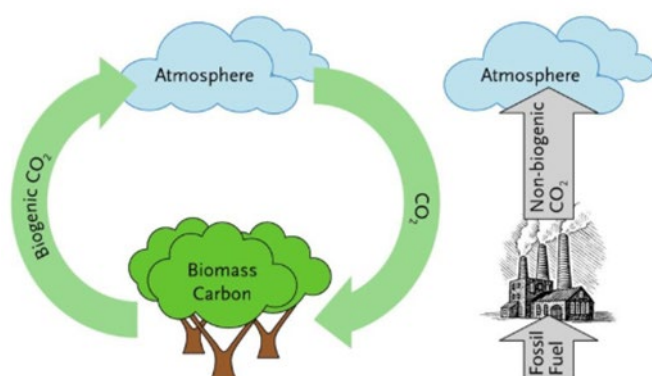


Figure 3. The use of sustainable produced biomass is part of the natural decomposition and thus the natural carbon balance is maintained. This means that the use of sustainably produced biomass does not contribute to a net increase in carbon dioxide in the atmosphere, unlike the combustion of fossil fuels. Photo: National Council for Air and Steam Improvement, USA, taken from IEA bioenergy (IEA Bioenergy 2018).

4.3 Previous studies on small scale CHP

Since focus in this report is on the Swedish context, focus has been on previous studies in a Swedish context.

In a Swedish context

Several previous studies have investigated the profitability of small-scale CHP based on biomass. For example, Sundeborg et al. 2011 compared three technologies for small scale CHP based on biomass. The technologies were an ORC, a Stirling motor and a gas motor. The results showed that, at that time, none of the technologies were profitable enough. The current electricity price (at the time of the study) was not consider benefitting profitability. The sensitivity analysis carried out in the study showed that if the investment costs and the fuel price were low, two of the technologies would lead to profitability. The investment cost turned out to be more important than the fuel price for the profitability. The result in a degree project (Johansson 2016) where the author studies the profitability of a small-scale gasifier gives the same conclusion, that the investment cost has a great impact on the profitability of a gasifier. Kjellström (2012a) also confirm that the high investment costs need to be lower for small scale CHP solutions to be profitable.

Kjellström (2012b) investigated if biomass-based gasification was mature enough for demonstration in Sweden. One of the conclusions showed that an investment was profitable at an electricity price of 1000 SEK/MWh and at a price of wood chips below 190 SEK/MWh. Such an investment was possible if the heat and electricity was used internally. The study showed that a decrease in tax reduction due to internally used electricity had a large effect on the profitability of the technology.

In another study, Kjellström (2013) examined which ownership solution was most favourable when examining which revenues can be credited through electricity production from a micro-gasification plant based on biomass. The ownership solutions studied were a real estate company, an industrial company, and a hostel. The result showed that owners who can use all produced electricity themselves, e.g. property owners or private individuals, had the most favourable ownership, which is due to that these ownerships being saved from paying some electricity tax. It was concluded in the study that the only ownership that was considered profitable was if a real estate company invest in a micro CHP plant.

A previous study of an ORC unit at an Energy company (based on Opcons Powerbox technology) showed that such an installation would only be profitable from an environmental perspective but not from an economic perspective (Persson 2010).

In an EU context

A report by IEA Bioenergy (2019) presents an overview of small-scale CHP technology developments in the last 10 years. The report also gives selected monitoring data from practical or laboratory applications of micro steam engines, micro ORC applications, Stirling engines and thermoelectric generators.

Several ORC solutions were studied by Pantaleo et al. (2015) from an Italian context. The study showed that different ORC solutions had discounted pay back times of the investment below 8 years. The lowest payback time was shown for several of the ORC solutions in the industry sector.

5 Background

This Chapter describes the three technologies, focusing on theory, description and prerequisites. The chapter also gives an overview of the biomass use in EU and Sweden. The chapter ends with a short description of the district heating systems in Sweden.

5.1 Steam turbines - theory

The traditional steam turbine is the most common way to produce electricity. The technology is used in coal condensing power plants, in CHP plants and in nuclear power plants.

The traditional steam turbine is available in various designs and with large variations in electrical power, from below 0.1 MW to over 1000 MW and with steam pressure of a few bar to several hundred bars.

A steam turbine operates according to the thermodynamic model, so-called Rankine cycle. The Rankine cycle operates in a closed cycle where a working medium (usually water) goes through four sub-processes (see also Figure 4 and Figure 5):

- 1-2, Electricity is supplied to the pump
- 2 – 3: The working medium is heated at constant pressure, in i.e. a steam boiler, and evaporated to saturated steam (and possibly also overheated (2-3')).
- 3- 4: The saturated steam is expanded through a turbine and generates electricity. Both temperature and pressure are lowered in the steam. Some condensation occurs. If the steam is overheated, the steam instead expands to saturated (dry) steam and condensation of the steam is thereby avoided (step 3' – 4').
- 4-1: The wet steam condenses at constant pressure to saturated liquid. Instead, in step 4' – 1, the dry steam is condensed to saturated liquid at constant pressure.

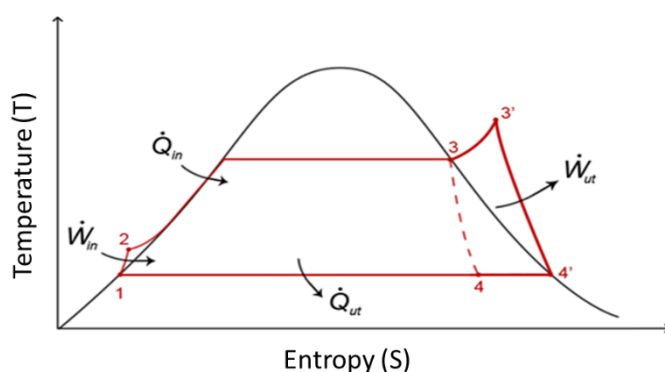


Figure 4 shows the Rankine cycle, so-called T-S diagram. The curve shows the saturation line of a working medium. On the left side of the line the working medium is in liquid state and on the right side of the line the working medium is in vapor phase. Between the lines, the medium evaporates or condenses. (i.e. a mix of steam and liquid). Source: Wikipedia, 2019

The steam turbine is limited by the formation of water droplets through the expansion of the turbine (steps 3-4 in Figure 4). Water droplets formed during steam condensation damages the turbine blades and lead to corrosion which reduces the efficiency of the turbine. Most easily, these problems are avoided by overheating the steam (steps 3' and 4' in Figure 4).

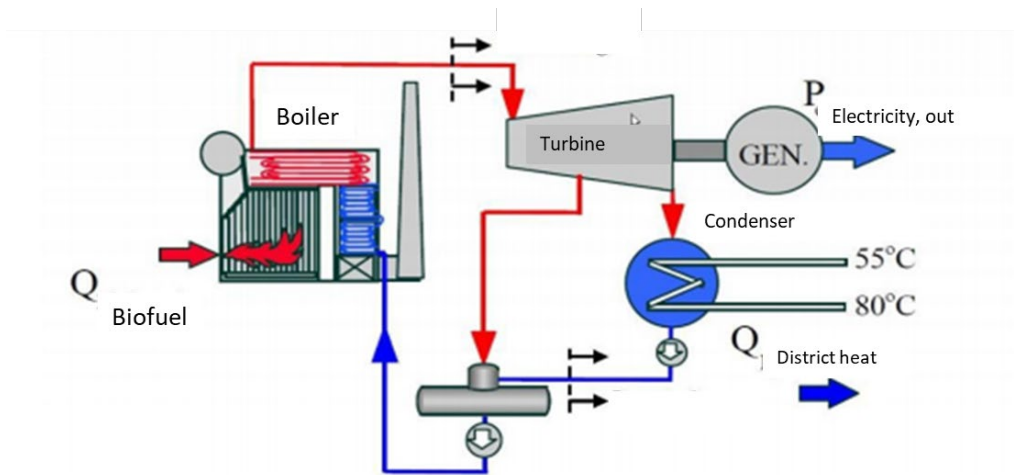


Figure 5 A schematic picture of a steam turbine cycle at a district heating plant. Source: Energikontor Sydost 2002.

The traditional steam turbine is still the best technology in sizes over 2MW_{el}. For small-scale cogeneration can also other technologies, such as the ORC and the WST technology, depending on the plant-specific condition, be interesting and profitable.

5.1.1 The ORC technology and prerequisites

The Organic Rankine cycle technology, so-called ORC technology, consists of a Rankine cycle that instead of water operates with an organic working medium. This allows the ORC turbine to run by supplying heat from a heat sources around 100°C and the operating pressure in the ORC-cycle is lower. The operation for the small-scale ORC can be described as follows:

1. The organic medium is evaporated at constant pressure by using a heat source around 100°C, from i.e a hot water boiler.
2. The evaporated organic medium expands over a turbine. The rotating turbine then drives a generator that produces electricity.
3. The organic medium is then condensed by a cold steam, i.e return district heating water.
4. After condensing, the pressure of the liquified organic medium is increased and then the cycle begins again.

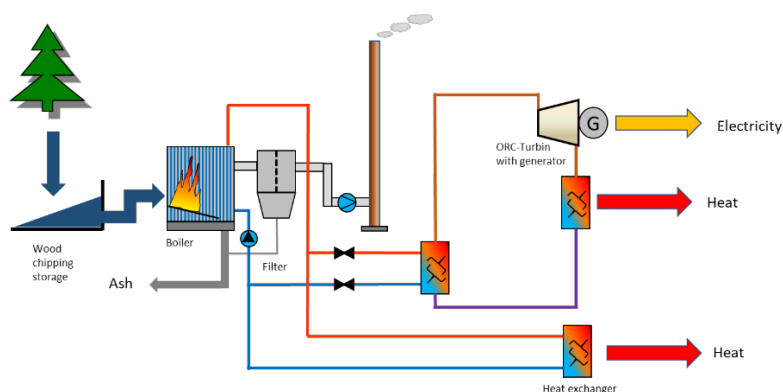


Figure 6. Schematic picture of the ORC-technology.

Prerequisites needed:

- A heat source above or around 100°C, to heat the ORC cycle
- A cold source less than 50 °C, to cool the ORC cycle
- The larger the temperature difference is, the more electricity can be generated.

5.1.2 The wet steam technology and prerequisites

A Wet Steam Turbine is a steam turbine powered by saturated steam instead of superheated steam. See Figure 7 for a schematic view of the wet steam connected to a steam boiler. To be able to resist possible water drops during condensation, the design is more robust compared to conventional steam turbines.

There exists, although unusual, hot water boilers at heating plants built with steam domes. In these cases, it is possible to adjust the boiler for steam production in prior to an installation of a Wet Steam Turbine. However, at most district heating plants a steam dome must be added to the boiler in prior to an installation of a Wet Steam Turbine.

Since the steam turbine is based on the same principle as the conventional steam turbine, it needs to be cooled to condense the water and release the heat. In a district heating plant, the turbine process is cooled with the district heating return water. The most economic system would be a Wet Steam Turbine installed at an existing boiler already prepared for steam production with a steam dome.

The main utilities in the total CHP system are: feedstock storage, the existing boiler and the steam cycle containing: Wet Steam Turbine, condenser, feed water tank, valves and pumps, see also Figure 7.

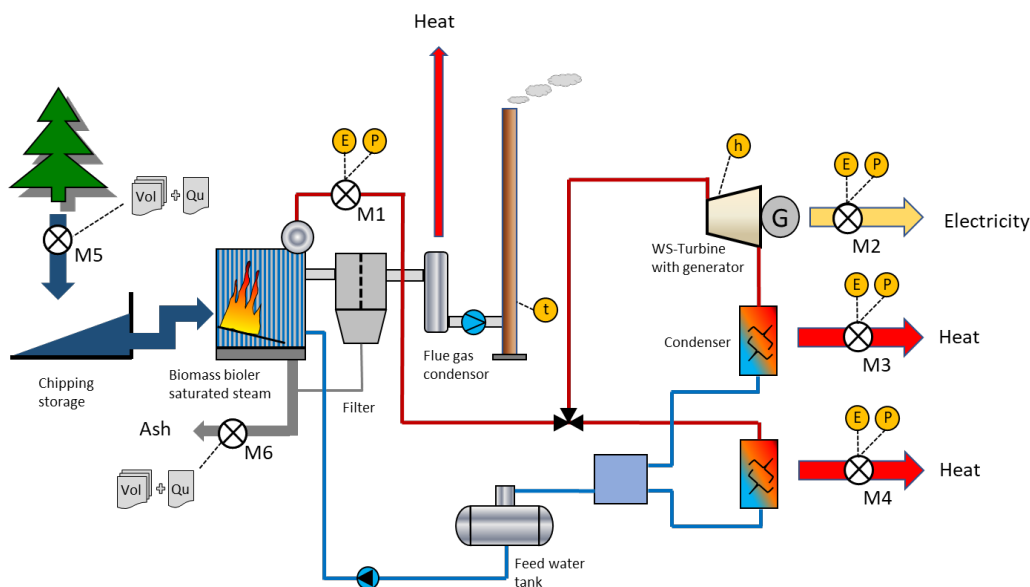


Figure 7. Schematic picture of the wet steam CHP process.

Prerequisites needed:

- Steam at approx. 200°C and 14 bar – need a steam dome on the boiler
- A cold source to cool the turbine cycle (return district heating water)

- Space for the turbine and auxiliary system (i.e. Feed water tank and pumps, pipes, condenser, and heat exchangers).

5.2 Gasification - theory

Gasification is a thermochemical process where solid or liquid material is converted into a gas. The material is converted, by incomplete combustion (i.e. absence of oxygen), into a gas with a high energy content. The gas can be used for combined heat and power generation, as feedstock to chemical processes or to produce different fuels such as methane, dimethyl ether (DME) and synthetic diesel (s.k. Fischer Trops diesel) or hydrogen.

The gas can be used for power generation both in engines and turbines. When using a gas engine, the gas cleaning requirements are not as severe as when using a turbine (Colmsjö 2008). Studies have also shown that the energy efficiency is higher in gas engines compared to turbines (Trygg et al. 2009).

A schematic overview of the gasification process is found in Figure 8. The gasification process with forest residues, wood chips, as feedstock can be divided into 4 steps:

1. Pretratement – The forest residues are first chipped (at the plant or before) and dried to a moisture content of appr. 15 %. The pre-treatment processes need both heat and power.
2. Gasification process – The wood chips reacts with a limited amount of air or oxygen at a temperature of 600 degrees or higher. The absence of oxygen limits the combustion of the raw material and instead creates a gas consisting of carbon monoxide and hydrogen, so called syngas. The gasification process also generates heat, which can be utilized.
3. Cooling and cleaning – The syngas needs to be cooled and cleaned. Depending on the final product, different levels of purity are needed. The cooling and cleaning processes also generates heat that can be utilized.
4. Utilization of the gas – The gas can be utilized in a gas engine or refined into various synthetic fuels.

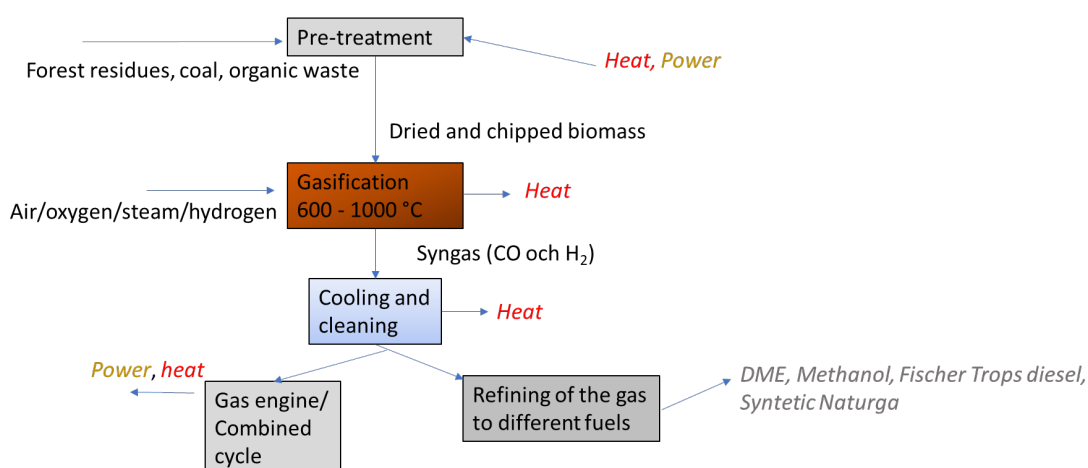


Figure 8. Schematic overview of a gasification process.

The gasification (step 2) process is complex. In general, it can be divided into two processes, which can take place in parallel and some extent simultaneously in the gasification plant, see Figure 9. In the first step is pyrolysis, which means that the feedstock converts to gases, liquids

and solid material. 75 to 90 % appears as gases and liquid and the rest is non-volatile carbon content. Several chemical reactions occur during the second step, gasification, and the output is a syngas (mainly consisting of CO and H₂). The chemical reactions are both endothermic and exothermic. The gasification processes can be both indirect and direct heated. In a direct gasification, the pyrolysis step and the gasification step take place in the same vessel. An oxidizing agent, oxygen or air burn part of the biomass to provide sufficient heat for the endothermic reactions. The pyrolysis process needs approx. 5 to 15 % of the combustion heat to raise the temperature and gasify the products. The other alternative is to have an indirect gasification process where heat is supplied indirectly. In this case, a bed of fluidized particles is used to transfer heat from the pyrolysis step to the gasification step.

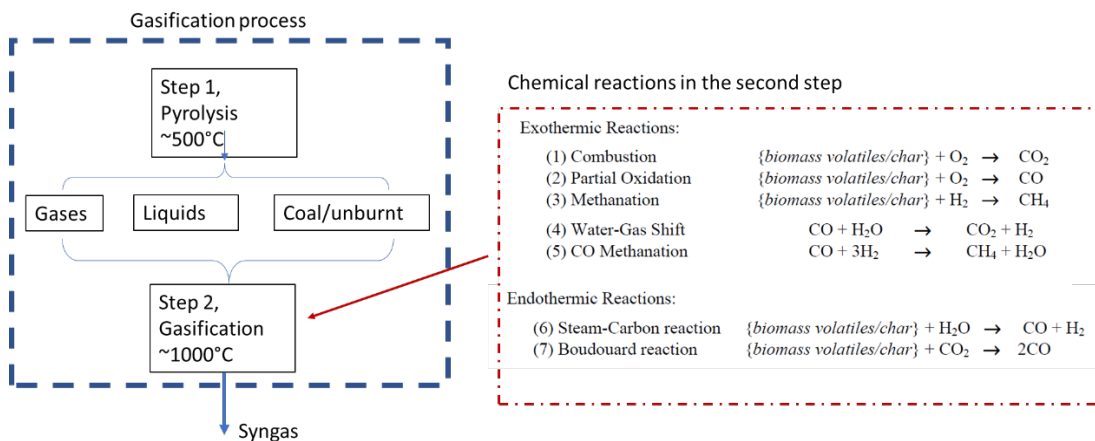


Figure 9. The gasification process and its sub processes and chemical reactions.

There are several different types of gasification processes available. For different gasification techniques, the different process steps (pyrolysis and gasification) can take place in different sequences in the reactor. The fixed bed gasifier is the oldest and most used gasifier. Other types of gasifiers include fluidized bed gasifiers, bubble bed gasifiers and entrained flow gasifiers (Held et al. 2011). The different types are suitable for different flows of biomass. The gasification capacity for each type of technique is shown in Figure 10.

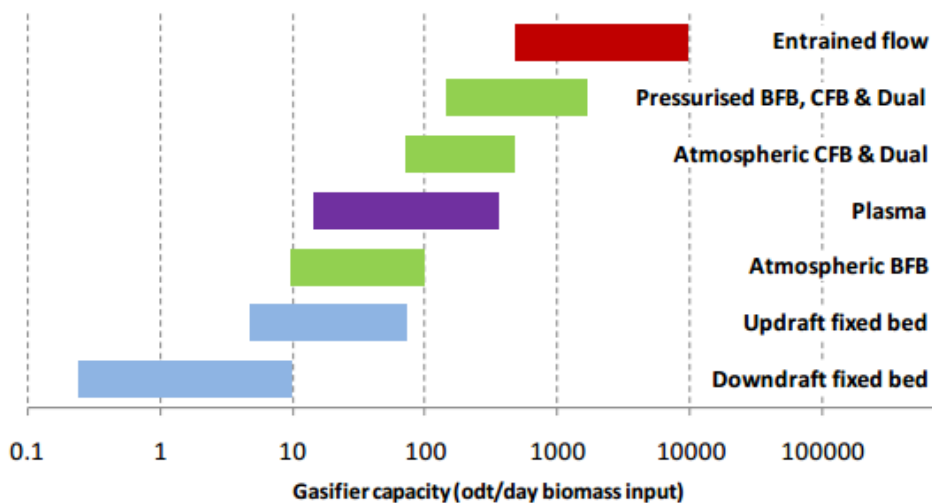


Figure 10. Gasification capacity for different types of gasifier techniques. Odt stands for oven dried tonnes. Source: (E4tech 2009)

Feedstock – biomass

Possible biomass material that can be used for gasification is residues from the forest such as branches and tops, chips, and bark. Also, liquids such as black liquor, pyrolysis oil and bio-oils can be used.

The composition of the feedstock has large impact on the final syngas. For biomass, the moisture content highly affects the composition of the syngas. The shape of the fuel and the ratio between area and volume has also large impact on the gasification process. A higher area creates a faster gasification of the fuel. Wood chips are gasified faster than wood pellets (Brunbäck 2011).

The moisture content of the feedstock also affects the energy need for drying in the gasification process. A high moisture content means a high energy demand and will lead to a lower gasification temperature (Ruiz et al. 2012).

Biomass has relatively high moisture content without any pre-treatment, between 30 to 60 % moisture. A suitable moisture content of the fuel for a gasification process is between 10 to 15 % (Basu 2009).

5.2.1 The dawndraft fixed-bed gasifier technology and prerequisites

For small scale gasification, the downdraft fixed-bed gasifier followed by cleaning and power generation in an engine is the most suitable process. The benefits with a downdraft fix bed gasifier are (Held 2011;Huang et al 2013, E4Tech 2009)):

- Most of the tar is combusted in a downdraft fixed-bed gasifier and only small amount goes into the gas, which allows a simpler gas cleaning.
- Minerals remain in the tar/ashes
- The gasifier is tested, simple and have relatively low costs

- High char content (4-7 % of the coal does not convert). If the char can be classified as biochar this could be sold on the market and contribute to CO₂ emission reduction.

The drawbacks with a downdraft fixed bed gasifier are (Held 2011, Huang et al. 2013, E4Tech 2009):

- The biomass needs to be dried (<20 % moisture)
- The syngas has a high temperature out of the gasifier
- High char content (4-7 % of the coal does not convert)- if not classified as biochar

Downdraft fixed-bed gasifiers are not suitable for large scale gasification, since upscaling creates an uneven gas distribution in the reactor (Ruiz et al. 2012, E4Tech 2009)). The limit is approx. 10 odt biomass per day (E4Tech 2009).

A gasification system includes a feedstock storage, a dryer, a feedstock handling system, the gasifier. A schematic picture of the total CHP system is found in Figure 11.

A homogeneous and dried fuel is important for the gasification process. Excess heat from the gasifier chassis could be used for drying the fuel.

After the drier the wood chips go into the gas reactor in which the pyrolysis and gasification steps takes place. Out from the gasifier comes a syngas at approx. 900 °C – 1200°C which is cooled in two steps before burning in a gas motor. In the first heat exchanger the gas is cooled from approx. 550 °C to 200°C. After that, the gas goes through a dry filter in which soot, dust particles and minerals are removed. The temperature after the filter is around 150°C. In the second heat exchanger the gas is cooled down to 60°C. The gas is mixed with air in the gas engine. The temperature of the engine at combustion is around 90°C. Heat is recovered from the gasification process in three steps: the cooling of the gas before and after the filter and from the motor (from the flue gases and from the refrigerant). The gas engine works best if cooling of the motor is below 80 degrees.

Several suppliers offer a gasification CHP system build as models including feedstock feeder, gas reactor, gas cleaning, gas engine and a generator (everything within the dashed lines in Figure 11 is usually inside the chassis of the module).

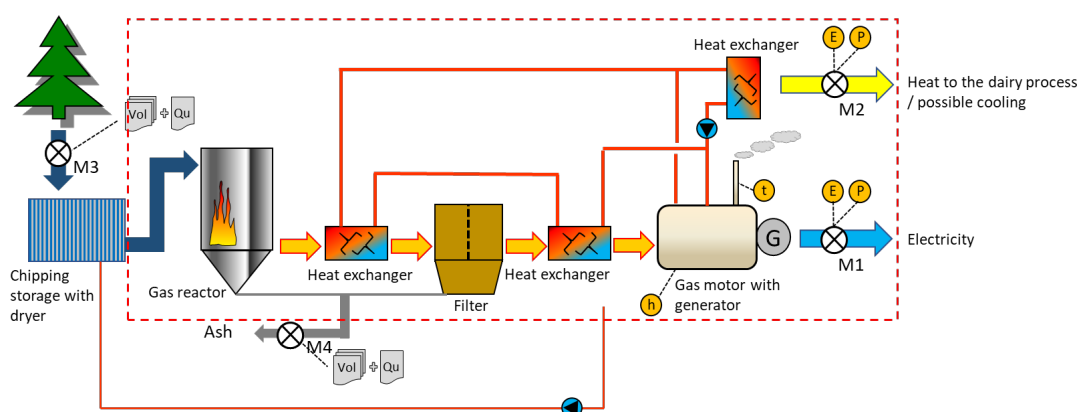


Figure 11. Schematic picture of a small gasifier CHP system.

5.3 Bioenergy use in EU

In EU, bioenergy use accounts for 10 % of total energy use. Over 60 % of all renewable energy in the EU is based on biofuels. Almost all production of renewable heat in the EU is based on biofuels (89 %) (Swedenergy 2018-05-08).

The conditions for the use of bioenergy differ between the countries in the EU. Five countries together account for more than half of the EU's use of bioenergy. These countries are Germany, France, Italy, Sweden, and Finland, as shown in Figure 12. Common to the five countries is that political decisions have favoured the development of bioenergy (AEBIOM 2017). However, Finland and Sweden have the largest share of bioenergy in total energy use (33.9 % and 32.6 %). In Scandinavian countries, bioenergy use is driven by a large forestry and by a well-developed district heating system that is largely based on biomass. Germany, Italy, and France have a more heterogeneous bioenergy market because of different political decisions. In Germany, for example, investments have been made in a major expansion of biogas production and in Italy in wood stoves. It should be noted that the deviation between forestry and agricultural biomass differs between the EU countries. The countries with most forestry-based biomass is Finland and Sweden.

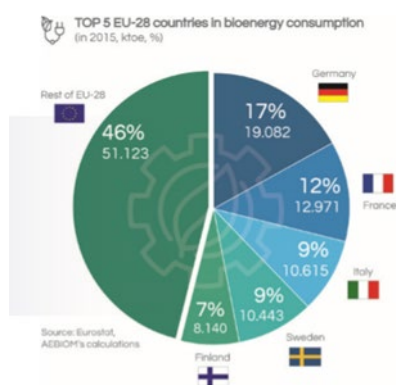


Figure 12. Five countries account for more than half of the bioenergy use in Europe. Source: AEBIOM 2017.

The use of bioenergy is increasing in the EU. In the UK, for example, a wide range of support and policy decisions have been used to increase the use of bioenergy. One example, so-called feed-in tariffs have been used for those who invest in small scale electricity generation with low carbon dioxide emissions. Support for district heating technicians is another example of a support that have been used. France plans to increase the carbon tax from 44.6 €/tonne in 2018 to 100 €/tonne by 2023, a decision that further increase the use of bioenergy. In December 2019, Germany decided to introduce a carbon dioxide price in sectors not including in the EU ETS³ system by 25 €/tonne from 2021 and then a gradual increase to 55€/tonne by 2025. Luxemburg has decided to introduce a carbon dioxide tax of 25 €/tonne, and Ireland increases their carbon dioxide tax from 20 to 26 €/tonne. The price of the EU CO₂ emission allowances has been around 25€/tonne between 2019 and 2020⁴.

Sweden has the highest CO₂-tax in Europe and globally, around 115 €/tonne CO₂. Followed by Switzerland and Norway. A high CO₂ tax in Sweden has, among other things, led to a reduction by more than 90 % of the CO₂ emissions from heating, since it was introduced in 1991⁵. Norway has completely banned oil boilers for heating in public and commercial buildings from 2020. Other countries that are increasing their bioenergy use are Spain and Portugal, as well

³ EU Emission Trading System

⁴ <https://ember-climate.org/data/carbon-price-viewer/>

⁵ <https://www.svebio.se/press/pressmeddelanden/%E2%80%8Barets-basta-klimatjulkapp-hojd-tysk-koldioxidskatt/>

as the Baltic countries. Lithuania has gone from 10 % bioenergy in the district heating system in 2004 to 65 % in 2016, with an expected share of 80 % by 2020. The use of bioenergy in the industrial sector in Lithuania has developed in a similar way.

5.4 Bioenergy use in Sweden

In Sweden, bioenergy use has increased significantly since the 1990s and now accounts for over 30 % of total energy use. In 2018, bioenergy (including waste and peat) accounted for 38 % of the total energy use (Svebio 2020). Several climate measures are the basis for the share increase, where the carbon dioxide tax is the single largest measure.

Bioenergy supply has increased from 61 TWh in 1990 to 141 TWh in 2018. At the same time, oil supply has decreased from 168 TWh to 103 TWh. (Swedish Energy Agency 2020)

Figure 13 shows how the use of biofuels has increased over the years. The fastest increase has recently taken place in the transport sector, where consumption in 2018 was 17 TWh. (Swedish Energy Agency 2020)

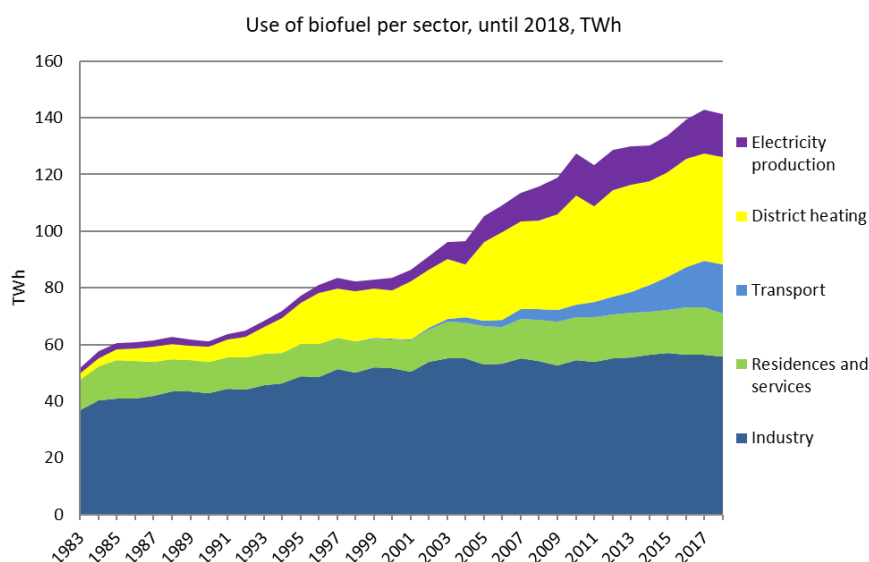


Figure 13. Use of biofuel per sector in Sweden up to 2018. Source: Swedish Energy Agency 2020

Of the total use of biofuels in 2018, approximately 106 TWh was based on forest biomass, approximately 25 TWh was based on biomass from agriculture and approximately 10 TWh from biogenic household waste (Swedish Energy Agency 2020). Figure 14 shows the use of

biofuel per fuel category for 2018.

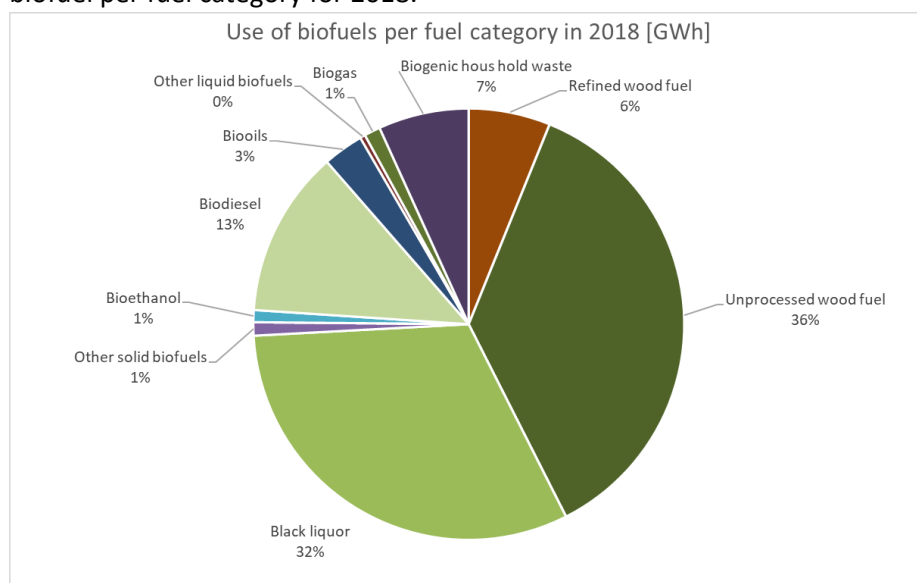


Figure 14. Use of biofuels per fuel category in 2018. Source: Swedish Energy agency 2020.

The two largest categories are unprocessed wood fuel and Black liquor. Black liquor is formed when wood chips are boiled into pulp in the pulp and paper industry. When the pulp has been filtered off, the black liquor is left. It is then evaporated, to lower the moisture content, and burned in a recycling boiler. Black liquor is used internally in the pulp process to produce process steam and electricity. The raw material is pulp wood, see also Figure 2. Unprocessed wood fuel is biofuel from wood raw material that has not undergone any chemical process. Wood fuel is divided into three categories: forest fuel, energy forest and recycle wood fuel.

- **Forest fuel** is wood fuel where the raw material has not previously been used in any other way, such as stumps, branches and tops, bark from sawmills and pulp mills, saw dust or other biproducts from the saw mills, pulp mills or forest industry.
- **Energy forest** is wood fuel where the raw material comes from cultivated fast-growing tree species, mainly wood chips from Salix or Poppel.
- **Recycle wood fuel** is wood fuel that has previously had other uses, such as demolition timber, packaging timber, cast timber (not classified as hazardous waste) and impregnated wood (classified as hazardous waste).

Refined wood fuel is biofuel from wood that has undergone a chemical process such as pellets, briquettes and wood powder.

For small scale CHP from biomass, the fuel concerned is unprocessed wood fuel, such as wood chips mainly from branches and tops or biproducts from the sawmills. Refined wood fuel could be used for small scale CHP applications; however, the fuel is more expensive.

5.5 District heating based on biomass

One of the main target groups for small scale CHP is the district heating sector. The reasons are:

- The heat infrastructure already exists
- The raw material is mainly biomass

- The infrastructure for biomass already exists

In 2018, only 8 % of the fuel supplied to the district heating generation in Sweden was from fossil fuels such as coal, petroleum products or natural gas. Most of the district heating is generated from biomass in biomass boilers or from municipal waste, see Figure 15. In 2018, excess heat from the industry, mainly from the pulp and paper industry, accounted for approximately 8 % of the energy supply for the district heating production. The share from large scale heat pumps (not individual house scale) was around 7 %. (Swedish Energy Agency 2020).

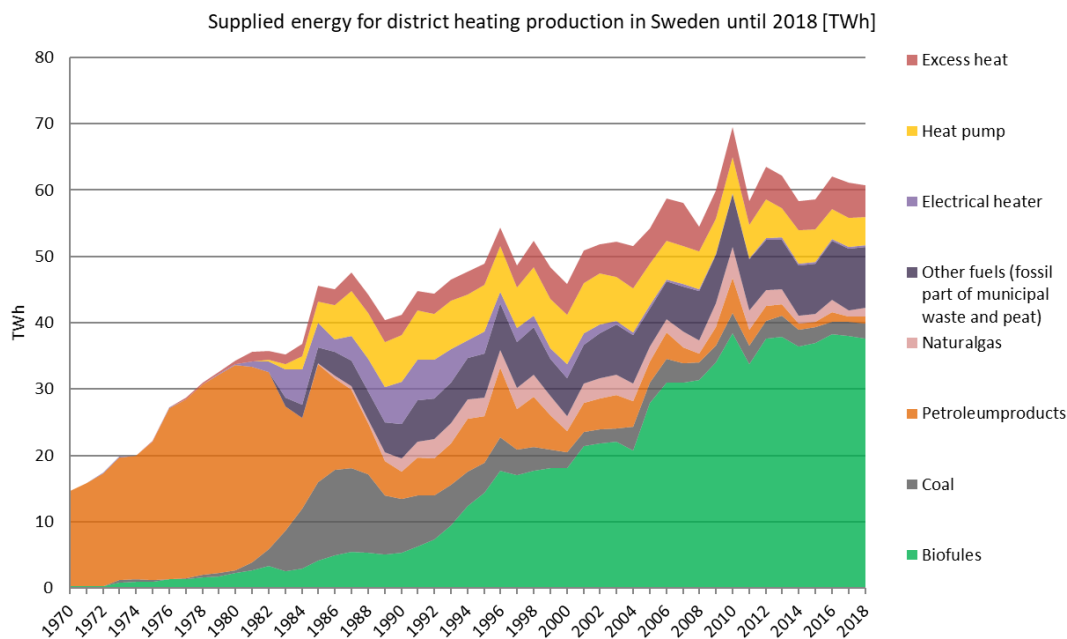


Figure 15. Supplied energy for the district heating production in Sweden until 2018, TWh. Source: Swedish Energy Agency 2020.

Most of the district heating plants with larger biomass boilers are built as CHP plants. However, the district heating networks in Sweden consists of many small local networks with boilers less than or around 10 MW. The bioheat and biopower production in Sweden is illustrated by the Swedish biomass association (Svebio) each year. From the maps, which are shown in Figure 16, it can be seen that out of the 556 district heating networks in Sweden, there are only 104 which has both heat and power production, over 400 has only heat production.

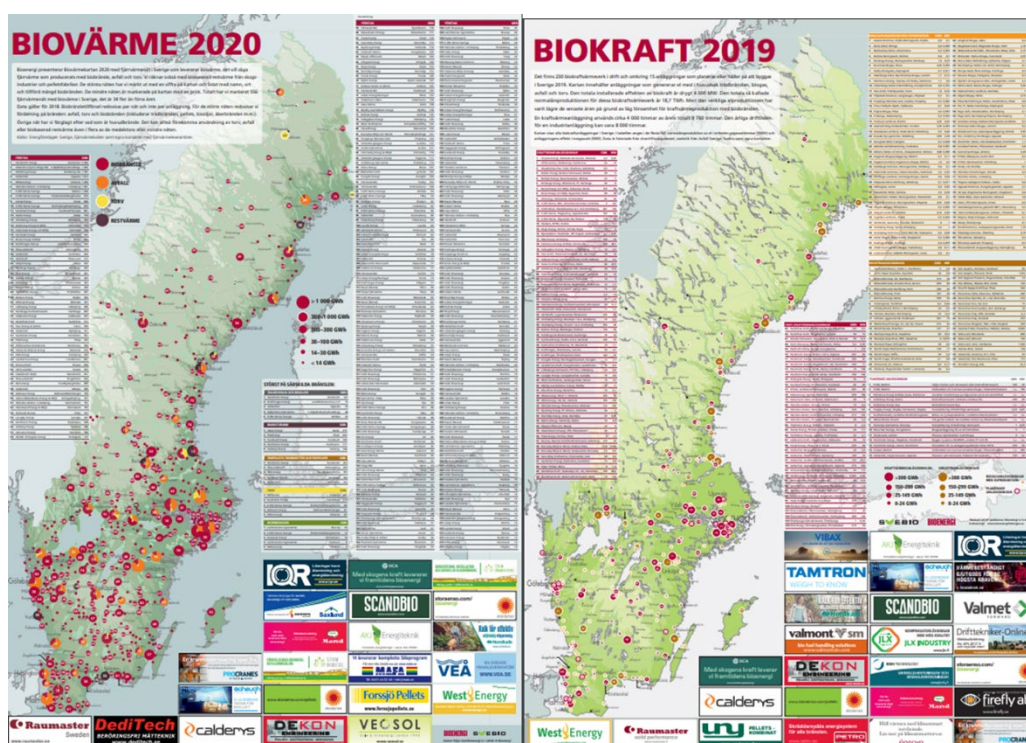


Figure 16. Maps showing the Swedish district heating network. The left map shows all district heating networks in Sweden. The right map shows the district heating networks with combined heat and power. Source; Svebio 2020b and 2020c

6 The three demonstration plants

This chapter shortly describes the three demonstration plants that have been the basis for this report. A more detailed description of the pilot plants and experience from installation and running is found in technical reports for each plant⁶.

An Organic Rankine Cycle at a district heating company

The first demonstration technology is an Organic Rankine Cycle (ORC) at the district heating company Ronneby Miljöteknik. The ORC is installed at the district heating plant in BräkneHoby and connected to a 5 MW boiler. The size of the ORC is appr. 50 kWe. The estimated maximum electricity generation is 232 MWh per year. The feedstock to the boiler is a mix of biomass i.e. wood chips, bark, branches and tops.

The main utilities in the total CHP system are: feedstock storage, the existing boiler, the ORC technology, valves and the heating water system.



A Wet Steam Turbine at a district heating company

The second demonstration plant is a Wet Steam Turbine with the size of 500 kWe. The estimated maximum electricity generation is 2 400 MWh/ year. The Wet Steam Turbine is placed in an existing district heating plant, Sörbyverket, in connection to a boiler of 9 MW heat. The produced electricity will make the district heating plant self-sufficient of electricity and the rest will be sold to the grid. The feedstock to the district heating plant is wood chips.

The main utilities in the total CHP system are: feedstock storage, the existing boiler, the Wet Steam Turbine, valves, feed water tank and the heating water system.



A gasifier at a dairy

The third demonstration plant is a small-scale gasifier, of 40 kW_e and 100 kW_h at a small local dairy the Emå dairy. Except from heat and electricity the gasifier also produces 500 litres of biochar during one week on full capacity, which for example can be sold as soil conditioner improvement. The biochar produced today are used for research on the possibilities of biochar.

The full potential for the gasifier at the dairy is 240 MWh electricity per year and around 600 MWh heat production per year. At full load, the heat from the gasifier will cover up to 80 % of the heating demand at the dairy and the electricity generation will cover approx. 15 % of the electricity demand in the dairy process. The feedstock to the gasifier is wood chips.

The main utilities in the total gasifier CHP system are: a feedstock storage, a dryer, a feedstock handling system, the gasifier, heat water system (including an accumulator tank) as well as a back-up boiler.



⁶ The reports are available here: <http://energikontorsydost.se/smallscaleCHPLife>

7 Methodologies

Since this report includes several sub-studies different approaches will be used for evaluating the different sub-studies. The methodologies considered for each sub-study are described in Table 2. The different methodologies are briefly described after the table.

Table 2. Methodologies used for each sub-study.

	Sub-study	Methodology considered
1.	Tecno-economic analysis for each technology and comparison	Payback method, net annual profit and simplified LCA
2.	LCA analysis for each technology	Cost -benefit analysis by simplified LCA using an expanding system approach
3.	Socio-economic analysis for each technology will focusing on south east Sweden including:	
	a) New jobs (direct and indirect)	Analysis of economic activities during the demonstrations and quantitative reasoning
	b) Security of supply	Quantitative reasoning
	c) Impact on local economy (circular economy) by evaluate the importance of local/regional small-scale CHP facilities in the system	Quantitative reasoning
	d) Health and safety	Quantitative reasoning
4.	Mapping of new small-scale CHP built during the project period	Mapping
5.	Evaluate the potential for small scale CHP for south east Sweden	Cost-benefit analysis (LCA) and quantitative reasoning

7.1 Description of the considered methodologies

This section describes the methods used for the economic, socio-economic, and environmental analyses.

7.1.1 Payback method

The payback method is a simplified method and is useful when comparing different investments. However, the payback method does not, in the simplest form, account for the time value of money, risk, financing, or other important considerations, such as opportunity costs⁷. Therefore, it is generally agreed that the method should not be used in isolation.

⁷ Opportunity cost is the forgone benefit that would have been derived by an option not chosen (<https://www.investopedia.com/terms/o/opportunitycost.asp>)

Alternative measures of return of an investment that is often used is the Net Present Value (NPV) method and Internal rate of return method.

Payback method

The pay back method is the number of months or years it takes to return the initial investment. The payback period is calculated by divide the investment cost by the estimated annual net cash flow, according to Eq 1.

$$(Eq\ 1.) \quad T = \frac{G}{a}$$

where **T** is the pay back time, **G** is the initial investment (expenditures) and **a** is the annual net cash flow. By using this formula, the net annual cashflow is expected to be the same each year.

The pay back method can give pay back periods that are part of years. However, if payments are made in the end of the year, the payback time needs to be rounded up.

Discounted payback method

The discount payback method account for the discount rate by discounting the cash flow to present value before adding it. For a constant cash flow each year the formula gets:

$$(Eq.2) \quad T = \frac{\ln(1 - \frac{G}{a} \cdot p)}{\ln(1+p)}$$

where **T** is the payback time, **G** is the investment, **a** is the annual net cash flow and **p** is the discount rate.

Decision rules for the payback method (Investopedia 2020)

- A profitable investment is payed off within the economic lifetime.
- When comparing different investments, the one with shortest payback time should be chosen
- The discounted payback time, at a discount rate at 5 %, should not be more than 20 years, since the benefits in the future will be of too little value¹⁴.

Advantages and Disadvantages

- **Advantages:** The discount payback method is more reliable than simple payback method since it accounts for time value of money.
- **Disadvantage (Xplained 2020):** It ignores the cashflow after the payback period. That might reject a project that having lower initial inflows but higher terminal cash flows.

Reasons for using the payback method in this analysis

The reason to use the payback method in this analysis is to give a first indication of the economics for the studied technologies. There are several parameters that are site specific and company specific and therefore a deeper analysis of the economics is necessary for each company to evaluate within their own specifications.

The method is widely used to estimate a first feasibility and profitability of a project, and since the purpose of the economic calculations in this project is to show the level of return period for companies to choose if they will go on and do a more thoughtful economic evaluation or not, the method fulfil the purpose. The payback time in this analysis is calculated both with the simple and discounted method.

7.1.2 Net annual profit

The net annual profit for an “average year” has been used in the economic calculations to complement the pay back method. A capital recovery factor of 0.1 was used as base case. A capital recovery factor of 0.1 is equivalent to e.g. economic lifetime of 15 years and a discount rate of 6 % or an economic lifetime of 20 years and a discount rate of 8 %.

Dividing the net annual profit with the capital recovery factor gives the NPV for the investment, if assuming that the cash flow is the same for all years during the economic lifetime as the “average”.

7.1.3 LCA analysis – with an expanded approach

Reliable methods for measuring the environmental impact of the use of the biomass as primary energy source are crucial for policymakers and decision makers to make informed decisions on suitable energy supply system. One such method that is gaining attention and fields of application is the life cycle assessment (LCA) methodology, in which the emissions from all processes along the production chain are quantified and summarized in different impact categories, as for example Global Warming Potential (GWP). The LCA methodology is standardized in ISO 14040:2006⁸ and has been applied extensively to biofuels in the literature (i.e. Börjesson 2006, Cherubini 2009) and also for policymaking, as for example in the sustainability criteria for biofuels under the Renewable Energy Directive (EC, 2009).

In this report, a process-based life cycle assessment (LCA) is assessed. The methodology approach in this assessment is a system expansion for all flows from a life cycle perspective. The general methodology steps are:

1. **Define the system boundaries and the surrounding systems that affect the studied system.** Systems left out do not affect the studied system, nor are they affected by streams leaving the studied system.
2. **Define the reference system** with which the greenhouse gas (GHG) emissions and the economic performance is compared. Here the reference system is the plant before the installation of the small-scale technology.
3. **Choose methodology to evaluate the effect of the surrounding systems.** In this analysis a scenario approach is used, in which different scenarios represents different levels of emissions and costs for various parameters.
4. **Calculate the energy balances** for the studied cases
5. **Analyse the payback period and GHG emission reduction** by using scenario analysis
6. **Vary key parameters** to analyse how sensitive the results are to changes in these parameters.

The methodology used is based on work of Johansson (2013)⁹ and adapted and adjusted for the purpose of this study.

The functional units used were kWh of electricity, and therefore, the environmental impacts from distribution of electricity were also considered. This study focuses on a regional perspective situated in Southern Sweden, in the county of Blekinge, Kalmar and Kronoberg.

⁸ <https://www.iso.org/standard/37456.html>

7.1.4 Socioeconomic activities – job creation

Several studies can be found in the literature that have analysed the effect of increased use of biomass in different applications and in different countries. The recent established forest strategy for Småland points out the importance of an increased production and use of forest raw materials for enable investments in Småland industry and for economic growth and jobs in the region¹⁰. A descriptive research by Domac et al. in 2005 presents a review of the socio-economic aspects of bioenergy systems as drivers for implementation of bioenergy projects. In that review the authors conclude that development of bioenergy has potential for job creation, improved industrial competitiveness, regional development, and the development of a strong export industry. They also conclude that employment is a function of bioenergy and that the quantity and quality depend mainly on the following parameters (Domac et al 2005):

- Stage or stages in the overall bioenergy system (i.e. production, conversion, and end use)
- Conversion processes and stage of conversion process (i.e. tree plantation)
- If the system is in developing countries/tradition/informal or if it is in developed country/modernized/subsidised or formalized.
- If it is labour intensive or mechanize

In 2003 IEA calculated the employment per PJ annual fuel consumption among several selected European projects (Eubia 2020). Most of the bioenergy cases analysed for socio-economic aspects are very site specific and situation-specific which makes it difficult to be properly generalized (BIOPROM). However, in Table 3, some of the project most related to the pilot plants in this study are listed (Eubia 2020).

Table 3. Employment per PJ/annual fuel consumption for five projects related to the demonstrations in this project. For detail information see (Eubia 2020).

Biomass source/ Technology	MW _{th}	Direct jobs	Indirect jobs	Induced jobs	Total jobs	Country
SRC ¹¹ , gasifier	2	51	11	36	98	UK
SRC, gasifier	5	36	21	23	80	Ireland
Forest residues, CHP	40	52	33	30	115	France
Ind. Residues, CHP	17	41	11	13	65	Italy
Logg. Residues, heat	10	52	2	21	76	Sweden

Direct jobs are related to production of fuel, construction, operation, and maintenance of conversion plant and for transporting the biomass. Indirect jobs are related to activities

¹⁰

<http://extra.lansstyrelsen.se/skogsstrategismaland/sv/start/Documents/sm%C3%A5lands%20skogsstrategi.pdf>

¹¹ SRC – Short rotation crops

connected but not directly related, such as supporting, industries, service etc. Induced jobs are results of higher purchasing power, due to earnings from direct and indirect jobs. Most jobs created are indirect jobs for all cases, even if that varies depending on technology specifics and countries.

In this project focus is on direct jobs and the following methodology has been created and used to evaluate the jobs created due to the installations:

1. **Based on invoices in the project estimate the hours of work carried out for each part**
 - a. *During planning and design*
 - b. *During procurement, rebuilding and installation phase*
 - c. *During operation*
2. **Local possibilities**, estimation of how much of the work that have been carried out by local firms.
3. **Quantitative reasoning concerning job creation**
4. **Comparison with previous studies**

7.1.5 Quantitative reasoning

For most of the sustainable criteria considered in the socio-economic evaluation in this report (see Section 7.2), the method used is quantitative reasoning. That means that the societal benefits and effects of a small CHP plant will be analysed based on a reasoning approach.

7.1.6 Mapping

The real effect of this demonstration project is evaluated by following the development of new installations of small-scale CHPs in Sweden. By having continuously dialog with suppliers of small-scale CHP technology and by following the bioenergy associations and newsletter, every new CHP plant is mapped on a map.

7.2 Sustainable criteria

While performing a socio-economic evaluation there are several criteria and indicators to consider. All social and environmental sustainability indicators are not relevant and cannot be covered in this report, but a few important key issues have been selected. The criteria and indicators included in in this study are highlighted in Table 4.

Table 4. Environmental indicators, social and economic criteria. The highlighted indicators and criteria are considered in this study.

Environmental indicators	Social criteria	Economic criteria
Greenhouse gas balance	Compliance with laws	Employment generation
Natural resource efficiency	Food security	Micro-economic sustainability
Species protection	Land availability for other human activities than food production	Macro-economic sustainability
Land use change	Respect of human rights	

Water management	Working conditions for the workers	
Waste management	Monitoring of performance criteria	
	Noise impact	

8 System boundaries, delimitation, and general assumptions

System boundaries and reference system

The system boundaries used for the socio-economic and environmental analysis in this report are based on an expanded system approach, meaning that the inlet and outlet flows concerning GHG emissions and money are included not only for the CHP itself but also how it affects the surrounding energy system. For example: the electricity generation from the CHP plants will affect the power grid (either because the electricity is sold to the grid or because electricity is saved from the grid due to internal use). This power grid will therefore save electricity generation. The GHG emissions related to the saved electricity will depend on the power system where the CHP is placed, in Sweden, in northern Europe or in southern Europe. A schematic picture that is illustrating the system boundaries and the expanded approach is found in Table 2.

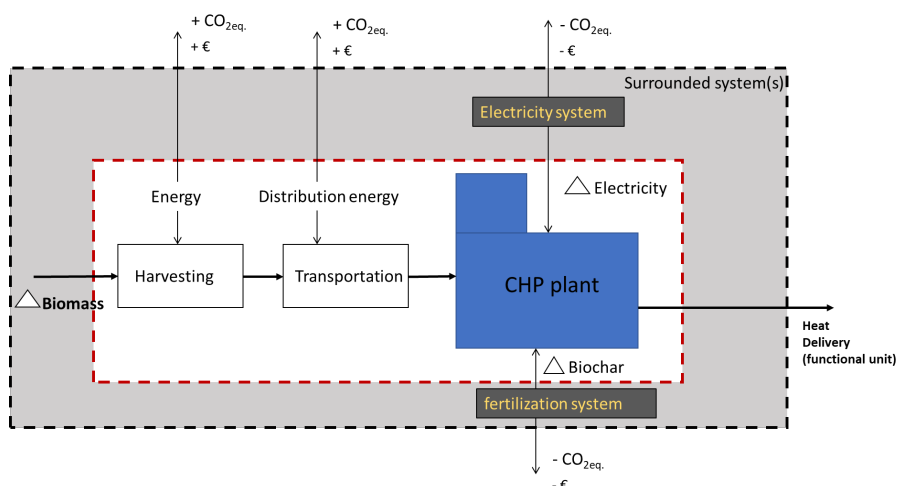


Figure 17. The system boundaries using an expanded approach. The arrows represent the net energy streams entering or leaving the system and how these interact with the surrounding systems. The GHG emission effect and the economic value of each flow are indicated with +/-, where + means an increase in $CO_{2eq.}$ or a revenue and – means a decrease in $CO_{2eq.}$ or a cost.

All flows are evaluated in relation to the reference case, which is the plant before the installation of the CHP technology. Meaning that all parameters are the difference between the system after the CHP installation compared to the original system.

Two of the reference cases using biomass as feedstock, while the reference case for the gasifier is an oil burner:

- **The reference case for the ORC¹²** analysis is a small district heating system based on wood chips.

¹² Illustrations and technical descriptions are found in reports for each technology here: <http://energikontorsydost.se/smallscaleCHPLife>

- **The reference case for the Wet steam technology²²** is a district heating system based on wood chips.
- **The reference case for the gasifier at the dairy²²** is an oil boiler with heat only generation to the dairy.

Harvesting of biomass

Some fossil energy is used for the working machines during harvesting the biomass fuel. This is estimated to 3.4 kg CO₂eq. /MWh based on number in Johansson (2013).

Transport of biomass to the CHP facilities

For all three demonstration plants the forest residues are assumed to be collected in average in a radius of 30 km and with an energy use of 0.075 MJ per kg DM delivered to the plant.

Input data for the analysis is listed in Table 5.

Table 5 Input data for the LCA.

Parameter	Value	Unit
Heating value of the biomass	2.4	MWh/tonne
Weight of biomass per truck	32	Tonne biomass/truck
Fuel to truck	0.35	l/km
Distance to CHP plant	30	km
Heating value diesel	35.2	MJ/l
CO ₂ from engine	73	gCO ₂ /MJ diesel

Electricity generated in the plants

Numbers from running the demonstration plants are used, which are described in Chapter 9 for each technology.

Heat generation in the plants

For the ORC and WST systems, the heat generation will be part of the existing system. The total demand will be unchanged.

For the gasifier, the total demand of heat will be unchanged due to the installation of the gasifier. However, the heat generated from the gasifier will replace heat produced from an oil boiler, i.e. the heat generation from the gasifier will reduce oil use and GHG emission.

Biochar

Biochar is a by-product from the gasification process. The biochar is assumed to be sold for 3 SEK/l. The GHG emission reduction from using biochar depends on how the biochar is used. Since it is a new product on the market, we are not yet sure of the level of GHG emission reduction and this is therefore not included in the LCA.

Emissions from biomass combustion

New biomass is constantly being formed, which means that CO₂ emissions from sustainable produced biomass in the longer term can be considered carbon neutral as the CO₂ emissions emitted during combustion or gasification is constantly bound to new biomass in a closed cycle.

8.1 Scenarios for GHG emissions saved by electricity generation

Electricity is saved in the system due to generation at all three demonstration plants. The environmental impact on the saved power generation will depend on the market for electricity at the specific location, hence there will be different emissions linked to power generation depending on where in Europe the small-scale CHP plant is located. The electricity generation and market are also rapidly changing, which effects the emissions related to power generation. To be able to take the difference into account several scenarios for replaced power generation is considered in the environmental analysis. The scenarios considered are:

- Average Swedish electricity mixture (13g CO_{2 eq.}/kWh)
- Average Nordisk electricity mixture (125g CO_{2 eq.}/kWh) (Naturvårdsverket, 2018)
- Electricity generated from natural gas (374g CO_{2 eq.}/kWh)
- Electricity generated from coal (750g CO_{2 eq.}/kWh) (EME analys och Profu)

There are several methods to evaluate emissions from electricity use. Which method is most suitable depends on which system is to be evaluated. For a system that involves major changes with long life, the recommendation is to use a forward-looking perspective or a so-called complex margin, which is a combination of operating margin in the existing system and an expansion margin for an expanding electrical system (Gode et al. 2009, EME analysis and Profu). However, such method requires knowledge and assumptions about the changes in the electrical system and thus advanced model calculations. Gode et al. (2009) consider that an equally good estimate is to use coal condensing power in the short term and natural gas-based power in the longer term. A brochure for calculation methods for different systems from Elforsk (EME and Profu) recommends a forward-looking perspective with two emission levels from a European electricity system: 600g CO₂/kWh and 150g CO₂/kWh. The different levels have been calculated in the basis of different assumptions about the price of CO₂ (20€/ton CO₂ in case one and 40-50€/ton CO₂ in case 2).

The average Nordic electricity mix represents average production of electricity in the Nordic region, which is the market in which the demonstrations are located. The average Nordic electricity mix is not suitable for evaluating the introduction of new systems (Gode et al. 2009 and EME analysis and Profu). However, the emission levels of average Nordic electricity mixture can be seen as a future European electricity system with high climate ambitions and high prices for carbon dioxide.

8.2 Economic input data and scenarios

This Chapter presents the input data for the economic evaluation, including investment costs and energy prices. The costs are divided into fixed costs, operational costs and savings or income:

- The fixed costs are related to the investment, discount rate and power grid fees
- The variable costs are related to maintenance and purchased biofuel
- The income and savings are related to saved or sold electricity, saved energy tax, sold electricity certificate, reduced electricity transmission costs and income for guarantees of origin
- For the gasifier case, income is also generated from selling biochar. Money is saved from reduced oil use.

8.2.1 Investment, external assistance, and maintenance cost data

The technical and economic data for the studied technologies are based on the real costs within this demonstration project. The investment costs represent the total costs for equipment (including the unit costs), including rebuilding of existing plant, auxiliary equipment etc. The maintenance costs are based on the experience from the pilot plants in this project.

Table 6 Input data on investment, external assistance, and maintenance

TECHNOLOGY	INVESTMENT COSTS (MSEK)	COST FOR EXTERNAL ASSISTANCE (MSEK) ¹³	MAINTENANCE COSTS (SEK/YEAR)
ORC (49 KW)	1.7	0.3	39 000
WST (500 KW)	16.8	2.5	100 000
GASIFIER (40KW)	4.3	0.7	250 000

Compared to costs described in the literature

The investment cost for the three pilot plants in this report is 3.5 €/We for the ORC, 3.4 €/We for the WST and 10.8 €/We for the gasifier. An overview of micro scale CHP technologies presented in a report by IEA bioenergy (2019) shows that the investment costs for ORC technologies between 0.3 and 50kWe is between 1-6€/Me, which is comparable to the investment costs for the ORC in this report. Kjellström (2012) showed an investment cost of 4 MSEK for a small-scale gasifier which is in the same range as in this report.

¹³ One-time costs for consultants and others during installation of the technologies.

8.2.2 Energy tax

In Sweden, the tax limit for electricity generation from biomass is 50 kW_e (installed capacity). The electricity that is generated in installations below 50 kW_e and that is used internally at the company is free from energy tax, see Figure 18. No tax reduction is possible if the electricity is sold to the grid, even if the installed capacity is below 50 kW_e.

In this report, the installed capacity for both the gasifier and the ORC are below the tax limit. It is therefore assumed that in the base case all generated electricity is used internally at the company.

The installed capacity for the WST is above the tax limitation. However, it is possible to get a tax reduction on the electricity required for the production of electricity.

The energy tax in Sweden is 353 SEK/MWh_e in 2020.

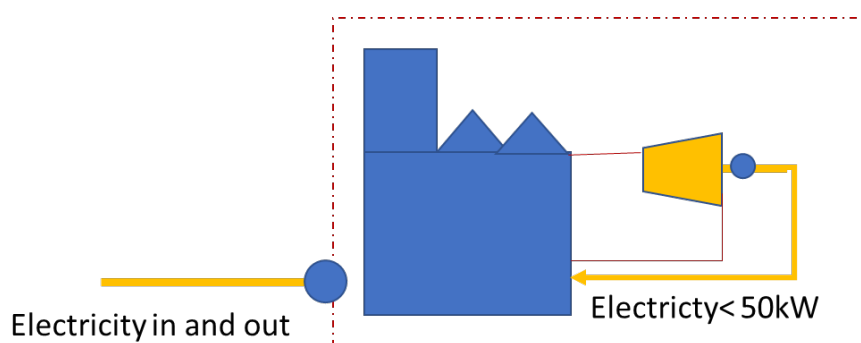


Figure 18. The tax limit for electricity generation is 50kW in Sweden. To get the tax relief the power must be used internally, i.e. the same organisation must own both the electricity generation and the district heating plant or industry.

8.2.3 Energy prices

Biomass price

The purchase price for wood chips and by-products for the district heating companies in Sweden was all time high in the beginning of 2011, which was due to a very cold winter and high demand of wood chips at that time. After 2011, the price has continuously falling until 2016/2017 when the price was raised again. The price increase during 2018 and onwards is mainly due to the wet weather during winter 2017, which made it hard to get the biomass out from the woods in combination with a cold winter in beginning of 2018 with a higher demand of wood products than usually. In addition, large coal power plants in Europe, and especially in Denmark, have converted into biomass which has increased the demand and the price of biofuels on the Swedish biofuel market.

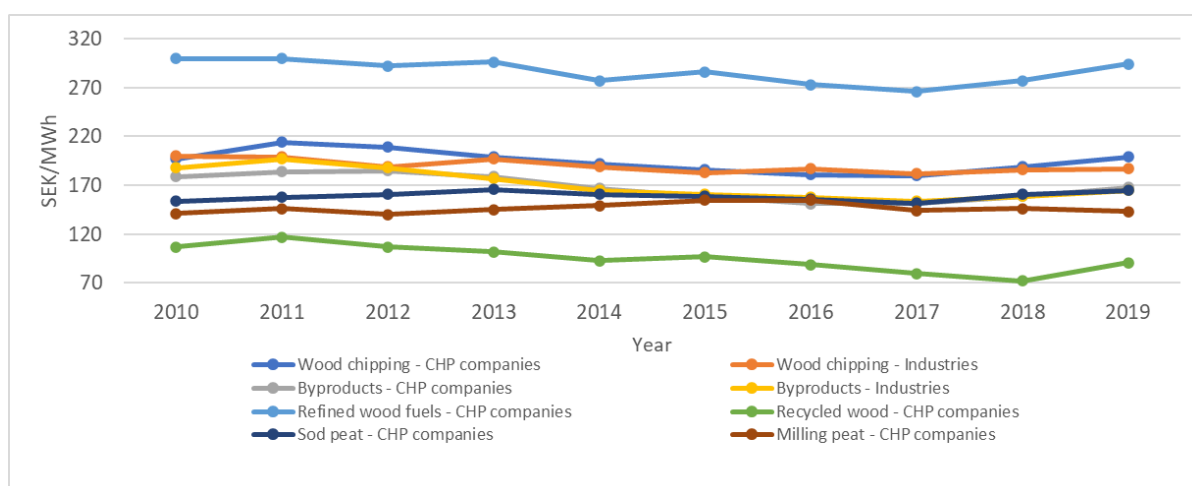


Figure 19. Purchase prices for wood chip and by-products on the Swedish market. Source: Swedish Energy Agency 2020b.

The purchased biomass price differs between countries. For example, the price of wood chips on the Baltic market is lower than on the Swedish market, as seen in Figure 20. Due to the wet weather during autumn 2017 that affected the Baltic countries extra hard, the price at the beginning of 2018 was up to the same level as in Sweden. However, the price has since then falling to almost half of the biomass price in Sweden.

BALTPOOL wood chips prices (Jan 2016 – Aug 2020)

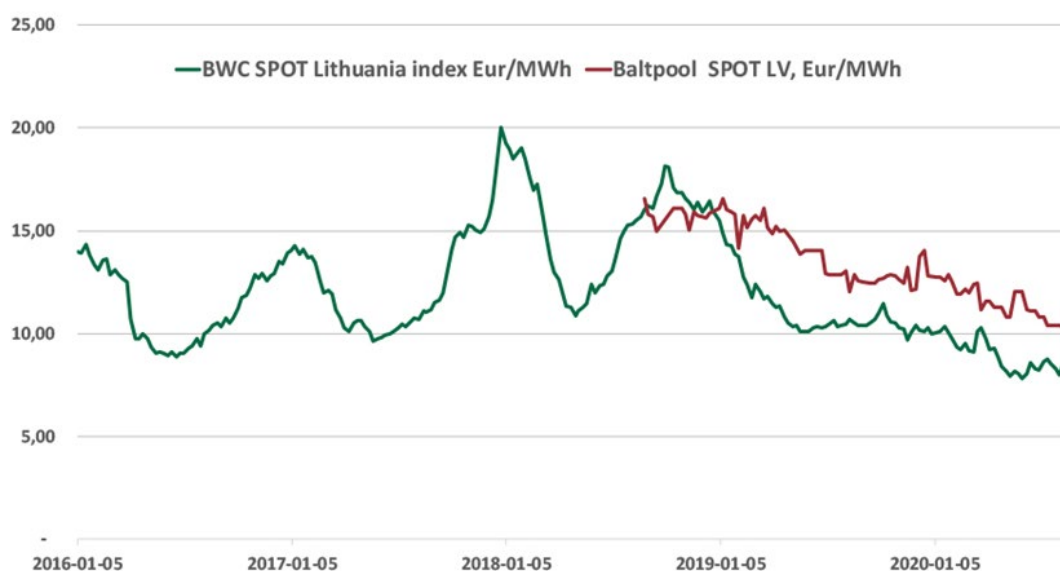


Figure 20. Wood chips prices at BALTPOOL... Source Svebo 2020d.

Electricity price

The electricity purchase price from a Swedish perspective, is defined on the Nordic electricity exchange, Nordpool, at which a spot price based on supply and demand is set on an hourly basis.

Figure 21 shows the development of the spot price since 2010 on the Nordpool market. From the figure it can be seen that the price has been significantly decreased since 2010 and 2011,

with the exception of 2018, which was due to the extremely dry and hot summer that did not fill up the water magazines for the hydro power. The price during 2020 has been all time low. And for the first time ever has negative electricity prices been reality in Sweden.

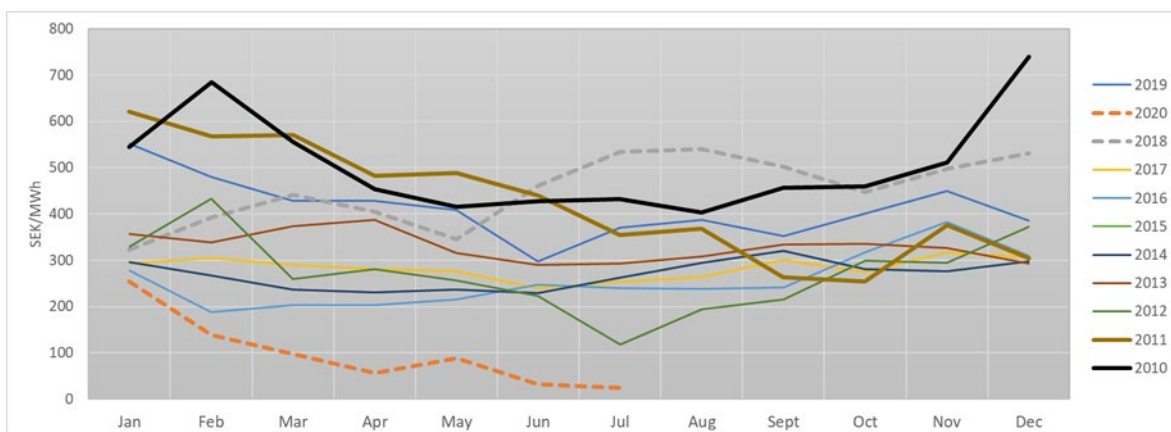
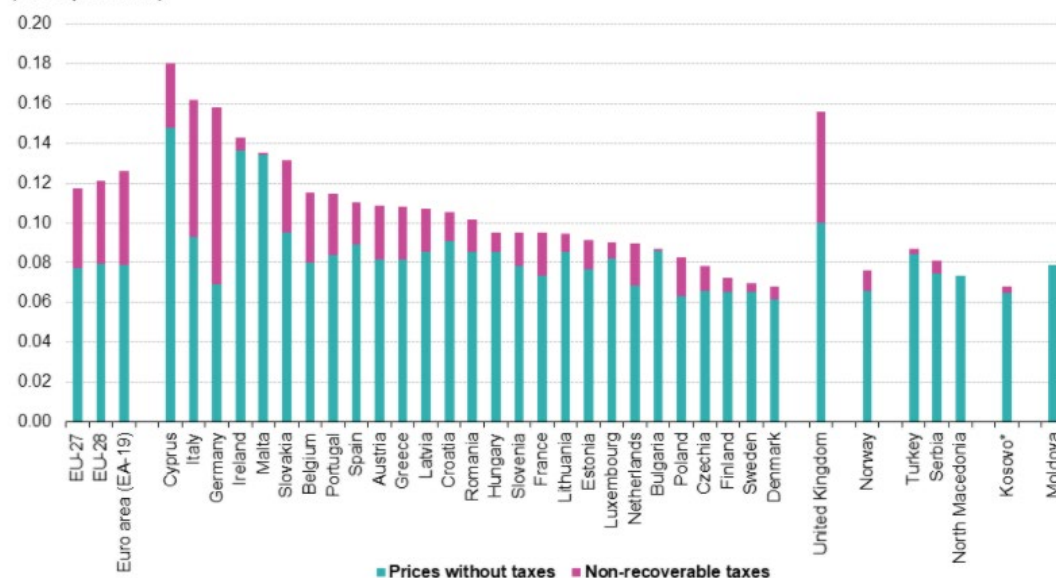


Figure 21 Historical data on spot prices for electricity on Nordpool from 2010 until 2020. Data source: [Nordpoolgroup.com/historical-market-data](https://www.nordpoolgroup.com/historical-market-data)

The electricity prices are in general higher in the rest of EU compared to Sweden and the countries on the Nordpool market. Figure 22 shows the electricity prices for non-household consumers in second half of 2019 in EU 27. As can be seen from the figure, the price of electricity was (without taxes) lowest in Denmark and highest in Cyprus.

Electricity prices for non-household consumers, second half 2019 (EUR per kWh)



* This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

Source: Eurostat (online data code: nrg_pc_205)

Size of this preview: 800 × 546 pixels.

[Original file](#) (1,003 × 684 pixels, file size: 86 KB, MIME type: image/png)

eurostat

Figure 22. Electricity prices for non-household consumers, second half of 2019. Source: Eurostat 2019

8.2.4 Five scenarios for economic evaluation

The costs and payback time will vary depending on the size of electricity generation, and the specific cost and operating conditions at each plant. The cost will also be country specific, due to regulations and level of tax and possible tariffs or tax reductions. The economic evaluation in this study is based on a Swedish perspective and shows the result from a Swedish context.

Therefore, economics has been calculated for different scenarios – to be able to illustrate the impact of different parameters rather than the exact number of payback time or revenue for the technologies.

The scenarios for the economic evaluation are based on several levels of energy prices, variations of technical performance and the impact on tax reduction.

The base case scenario represents a realistic case where the technologies deliver what is expected, both in terms of running hours and based on electricity generation. This represent a case that is most likely for others to consider. The following three scenarios represents the same technical requirements but with variations in costs for electricity and biomass. Scenario 4 represent the “real” scenario based on the actual operating hours and energy generation from the pilot plants. Scenario 5 represent a scenario without tax reduction. The scenarios are presented in Table 7.

Table 7. Scenarios and input data for cost analysis

PARAMETER	BASE CASE	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
SCENARIO POWER CAPACITY	Full capacity ¹⁴	Full capacity	Full capacity	Full capacity	Real capacity ¹⁵	Full capacity
PRICE OF ELECTRICITY	450 SEK/MWh	600 SEK/MWh	450 SEK/MWh	450 SEK/MWh	450 SEK/MWh	450 SEK/MWh
GREEN ELECTRICITY CERTIFICATE	No	No	No	140 SEK/MWh	No	No
PRICE OF BIOMASS	200 SEK/MWh	200 SEK/MWh	250 SEK/MWh	200 SEK/MWh	200 SEK/MWh	200 SEK/MWh
SAVED ENERGY TAX, DUE TO INTERNAL ELECTRICITY USAGE	YES	YES	YES	YES	YES	NO

To illustrate the importance of tax relief a Scenario 5 is added for the ORC and the WST case. The scenario represent a case were the electricity from the ORC is delivered out on the power grid or a case for the WST where no tax relief is put on the electricity for producing the electricity in the WST. Scenario 5 is not relevant for the gasifier case since a production industry does not pay energy taxes for electricity in Sweden. Therefore, Scenario 5 for the gasifier represents a case when no income is gained from the biochar production.

¹⁴ Full capacity means for the ORC: 49 kW, for the WST 500kW, for the gasifier 40kW

¹⁵ Real capacity is based on the real numbers during this demonstration project. The numbers are described in Section 0.

9 Data and assumptions for each demonstration plant

The following sectors will summarise the input data and assumptions used for each demonstration plant. All technical and operational aspects as well as lessons learned from installing and running three small scale pilot plants are thoroughly described in reports for each demonstration plants¹⁶.

9.1 The ORC unit

The input data is based on the experience from the demonstration of the ORC unit in BräkneHoby, Ronneby. Since the experience is very depending on the specific case, we have changed some parameters to present a more general and realistic case in which the next buyer of an ORC unit have learned from the experience of the pilot plant in BräkneHoby. The main changes compared to the actual production (Scenario 4) in BräkneHoby is that we have increased the power generation by increasing the average power capacity of the ORC unit but kept the number of operation hours. The main reason is that the temperature difference in the system in BräkneHoby is quite low and in another system a more realistic production would have a higher average capacity. However, the operation hours are depending on the outdoor temperature and that will not change for a unit in the same area as in BräkneHoby: The operation hours could, however, be both less and more depending on the location of the installation. Table 8, describes the input data for both the realistic and actual production cases. Scenario 1 to 3 and 5 are based on input data for the realistic production case.

Table 8. Input data for calculations of cost and CO₂ emissions for the ORC installation.

	Realistic production (Base case)	Actual production (Scenario 4)
Power generation [MWh]	231	173
Biomass use [MWh]	272	203
Operation hours [h]	4727	4727
Average power capacity [kW]	49	37
Boiler efficiency at the district heating plant [%]	87	87
Electricity demand for the pump in the ORC system [%]	10 % of generated electricity	10 % of generated electricity
Economic lifetime [year]	15	15
Discount rate [%]	2	2
Investment [MSEK]	2.027	2.027
Recovery factor	0.1	0.1

¹⁶ These reports are found here: <http://energikontorsydost.se/smallscaleCHPLife>

The equipment costs (CAPEX) for the ORC unit consists of:

- Equipment and installation costs (ORC)
- Repiping in existing building

The total cost for the ORC in BräkneHoby was 2.027 MSEK, including repiping costs for around 100 000 SEK.

The running costs (OPEX) for the ORC unit consists of:

- Yearly service agreement
- Cost for additional service (Oil and nitrogen refilment)
- Cost for hot water production (i.e. cost for increased amount of biomass)

The supplier offers a yearly service agreement. Which depends on size, but with a 50-kW unit the price is today around 35 000 SEK/year.

The savings and revenues from produced electricity for internal use (below tax level of 50kW), depends on the following parameters:

- Savings from bought electricity
- Energy tax savings
- Savings from lowered fee for capacity on the power subscription
- Savings from decreased costs for the variable power grid fee
- Income from green electricity certificate

The revenues from produced electricity for external use (i.e sold to the network >50kW), depends on the following parameters:

- Income from sold electricity
- Income from green electricity certificate
- Reduced electricity transmission costs due to production and delivery of electricity

Income for guarantees of origin for electricity generation

9.2 The Wet Steam Turbine

The input data is based on the experience from the demonstration of the WST unit in Ronneby some parameters in the base case to present a more general and realistic case in which the next buyer of an WST unit have learn from the experience of the pilot plant in Ronneby. The main changes compared to the actual production (Scenario 4) in Ronneby is that we have increased the power generation by increasing the average power capacity of the WST unit but kept the number of operation hours. The main reason is that the WST unit was only running for a limited period and there are still measures that can be made to increase the efficiency of the turbine. However, the operation hours are depending on the outdoor temperature and that will not change for a unit in the same area as Ronneby. The running hours could, however, be both less and more depending on the location of the installation. Table 9, describes the input data for both the realistic and actual production cases. Scenario 1 to 3 and 5 are based on input data for the realistic production.

Table 9 Input data for the calculations of cost and CO₂ emissions for the WST installation.

	Realistic production (Base case)	Actual production (Scenario 4)
Power generation [MWh/year]	2436	1928
Biomass use [MWh/year]	3248	2571
Operation hours [h/year]	4872	4872
Average power capacity [kW/year]	500	396
Energy efficiency of the district heating plant after installation [%]	75	75
Economic lifetime [year]	15	15
Discount rate [%]	2	2
Investment [MSEK]	19.4	19.4
Recovery factor	0.1	0.1
DoU [MSEK/year]	100	100
Additional costs [MSEK/year]	100	100

The equipment costs (CAPEX) for the WST unit consists of:

- Equipment and installation costs (WST)
- Repiping and rebuilding the existing district heating plant in prior to the installation

The total cost for the WST installation was 19.4 MSEK.

The running costs (OPEX) for the WST unit consists of:

- Yearly service agreement
- Additional costs which consists of costs due to electricity maintenance, additional costs due to unforeseen maintenance and due to the increased complexity of the plant.

- Cost for hot water production (i.e. cost for increased amount of biomass)

The total electricity demand during the district heating season (when the turbine is running) is 1200 MWh at the district heating plant (800 MWh are electricity used for the electricity generation and with the possibility of a tax reduction). The electricity generated from the WST is first used to cover the electricity demand at the plant and the rest of the generated electricity is sold to the grid, i.e. in the base case 1 236 MWh.

The savings and revenues from produced electricity for internal use depends on the following parameters:

- Savings from bought electricity
- Savings from lowered fee for capacity on the power subscription
- Savings from decreased costs for the variable power grid fee
- Income from green electricity certificate (The price is set to 0 in the base scenario)
- 800MWh is also free from energy tax, due to that it is needed for the electricity generation

The revenues from produced electricity for external use (i.e sold to the network), depends on the following parameters:

- Income from sold electricity
- Income from green electricity certificate
- Reduced electricity transmission costs due to production and delivery of electricity
- Income for guarantees of origin for electricity generation

9.3 *The gasifier*

The input data is based on the experience from the demonstration of a gasifier at a dairy in Hultsfred. Since the experience is very depending on the specific case, we have changed some parameters in the base case to present a more general and realistic case in which the next buyer of a gasifier have learn from the experience of the pilot plant in Hultsfred. The main changes compared to the actual production of the gasifier is that the gasifier is running 6000h a year, as was the expected number of operation hours. The reason for the lower operation hours in the specific demonstration plant is described in the technical report¹⁷. However, today both the supplier of the demonstration plant and new suppliers on the market have reference cases of gasifier in continuously operation. The installation of a gasifier at the dairy also included a rebuilding of the heating system of the dairy, including a new back-up oil boiler with much higher efficiency. That has led to a large reduction of oil use and GHG emissions even if the gasifier has not been up running as expected. Input data for the cost and GHG emission calculations are listed in Table 10.

¹⁷ Which can be found here: <http://energikontorsydost.se/smallscaleCHPLife>

Table 10. Input data for the calculations of cost and GHG emissions for a gasification unit.

	Realistic production (Base case)	Actual production (Scenario 4)
Power generation [MWh/year]	240	30
Electricity demand at the dairy [MWh/year]	1680	1680
Wood chips [m3/year]	1200	315
Operation hours [h/year]	6000	1573
Average power capacity [kW/year]	40	31
Average heat capacity [kW/year]	100	100
Boiler efficiency at the district heating plant [%]	90	90
Economic lifetime [year]	15	15
Discount rate [%]	2	2
Investment [MSEK]	4.7	4.7
DoU [MSEK/year]	250	250
Recovery factor	0.1	0.1
Heat demand at the dairy [MWh]	750	750
Biochar production [l/h]	2.98	2.98

The equipment costs (CAPEX) for the gasification consists of:

- Equipment and installation costs for the gasifier system including a dryer and feedstock handling system and storage.
- Necessary repiping and rebuilding of the dairy heating system in prior to the installation.

The total cost for the installation was 4 683 of which 2 989 is costs for the gasifier and dryer.

The running costs (OPEX) for the gasifier unit consists of:

- Yearly service
- Cost for wood chips

The savings and revenues from produced electricity for internal use (below tax level of 50kW), depends on the following parameters:

- Savings from bought electricity
- Savings from lowered fee for capacity on the power subscription
- Income from green electricity certificate (However, the price of the green certificates is set to 0 in the base case)

A dairy business in Sweden does not have to pay taxes on purchased electricity. Therefore, no tax could be saved on the produced electricity as in the case of an ORC at a district heating company.

The savings from heat generation in the gasifier is from saved oil for the boiler. The heat demand in the dairy process is 750 MWh per year. In the base case it is assumed that the gasifier produces 600 MWh heat per year. The heat generation thereby saves 600 MWh heat produced by an existing oil boiler which is assumed to have an efficiency of 90 %.

An additional income for the gasification system is biochar production, which is a by-product created in the gasification process. The amount of biochar produced is 2.98 l/h.

10 Results – Economic aspects

The costs and payback time will vary depending on the size of electricity generation, and the specific cost and operating conditions at each plant. Therefore, the payback time is calculated for different scenarios and with both the simple and discounted method, described in Section 8.2.4.

10.1 ORC

In this chapter, the payback time and NAP value is calculated for the ORC unit. The price of electricity, annuity factor and running time are factors that significantly affects the profitability. These parameters are therefore evaluated in a sensitivity analysis.

10.1.1 Payback-time

The payback time for the ORC (49kW) varies between 15 and 170 years depending on method and input data, see Figure 23. In Scenario 5 there are no bar for the discounted payback method, which means that the costs each year exceeds the income and savings and in that case the investment will never be paid back and the equation will give a ungulity number.

As can be seen in Figure 23, the largest effect on the economics and the payback time has the tax-reduction. For a small ORC unit it is therefore very important that the ORC unit is installed in the same company as the district heating production in order to be able to internally use the electricity that is produced and in order to (from a Swedish perspective) get tax reduction for the energy tax. It can also be seen that if the ORC unit does not generate as much electricity as the capacity calls for, the payback time will increase significantly (Scenario 4). A higher price for electricity will lower the payback time (Scenario 1 and 2) and a high price of biomass will increase the payback time (Scenario 4).

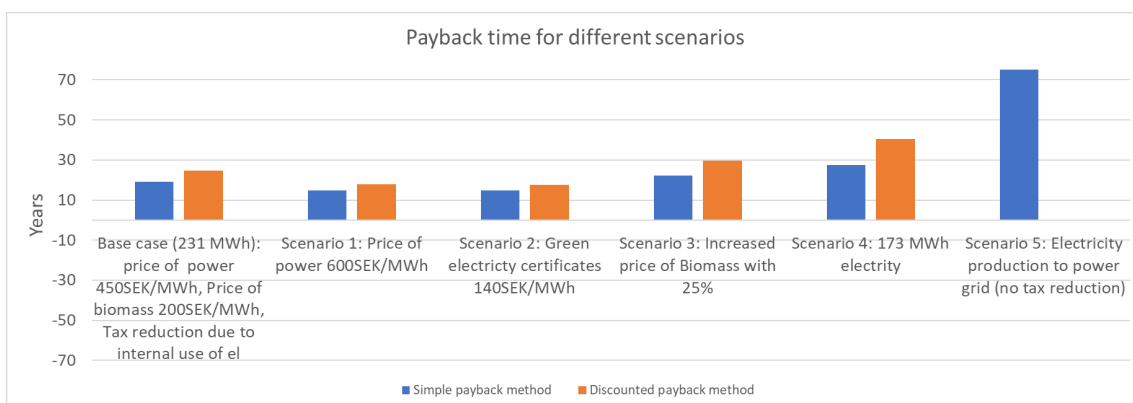


Figure 23. Payback time for the ORC at different scenarios, with and without accounting for the discount rate.

The discount rate is a factor that has a large impact on the economic calculations. Figure 24 shows that the payback time varies significantly when changing the discount rate. For scenario 1, with a high electricity price, the payback time changes from 38 down to 16 years when the discount rate is changed from 6 % down to 1 %. For the discount rate of 6 % for the base case and for the discount rate of 6 and 5 % for Scenario 3, the payback time using Eq.2 is negative, which means that it never will be repaid, and hence no payback time are illustrated in the figure below.

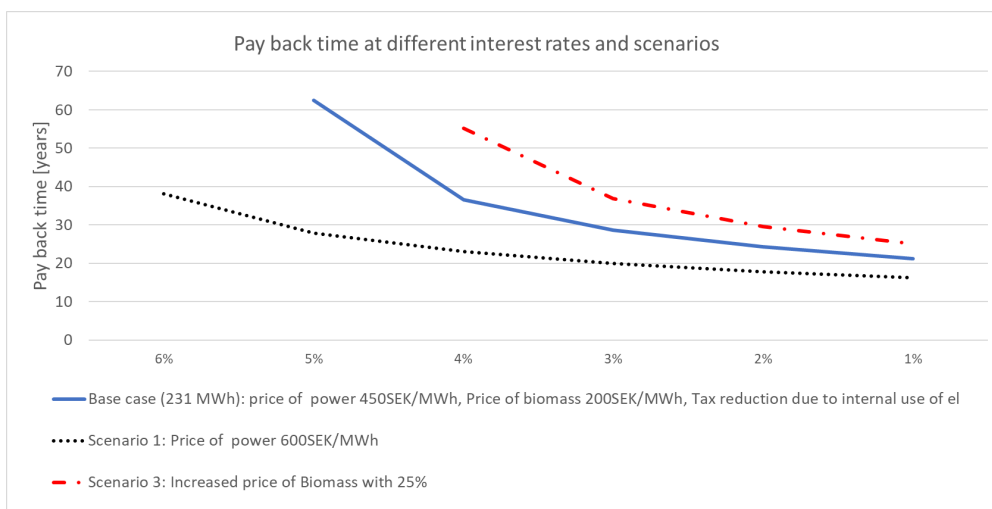


Figure 24. The payback time at different discount rates and for three of the scenarios.

Another parameter with great importance for profitability is the number of operation hours, which is proportional to the electricity production. In Figure 25 the payback time is calculated at different discount rates and at different operating hours (4727, 6000 and 8000), at two different levels of electricity prices (450SEK/MWh and 600 SEK/MWh). Lowest payback time is achieved if the ORC unit can run as much as possible. For a scenario with high electricity prices and many operating hours, the payback time can be down to 10 years. A longer operating time also makes the payback time less sensitive to the discount rate and the price of electricity. The payback time for the case with 6000 operating hours and a lower electricity price is not shown in the figure, the reason is that the payback time is identical to the case of 4727 operating hours and a higher electricity price.

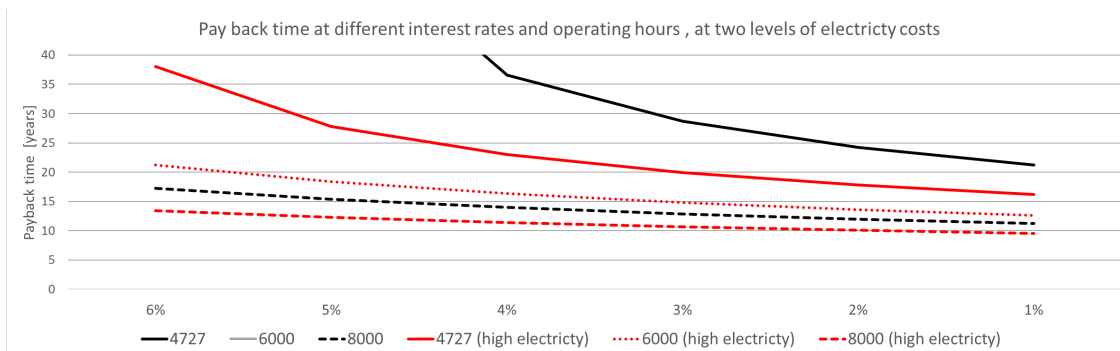


Figure 25. The payback time at different discount rates and operating hours at two different levels of electricity costs.

From the result the parameters that affects the payback time significantly is:

- The tax relief
- The price of electricity
- The discount rates
- The operation hours (electricity production)
- Price of biomass

The higher operating time that is possible, the more electricity can be generated, and the profitability will be less affected by change in electricity price.

The lowest payback time will be achieved with high electricity prices and low biomass prices. Figure 26, shows an example for an ORC installation with the capacity of 49 kW, with operating hours from September to April (5500h). In this case the electricity price is 800 SEK/MWh and the biomass price is 160 SEK/MWh. The case could represent a future Swedish case with higher electricity price, or an increased power grid fee, but it could also represent a case in a country with higher electricity prices than in Sweden. If the tax reduction is added to the price of electricity, it could represent a case with an electricity price of around 1150SEK/MWh. The exact costs and revenues will vary from country to country and should be calculated for each case to get the exact prerequisites for the profitability.

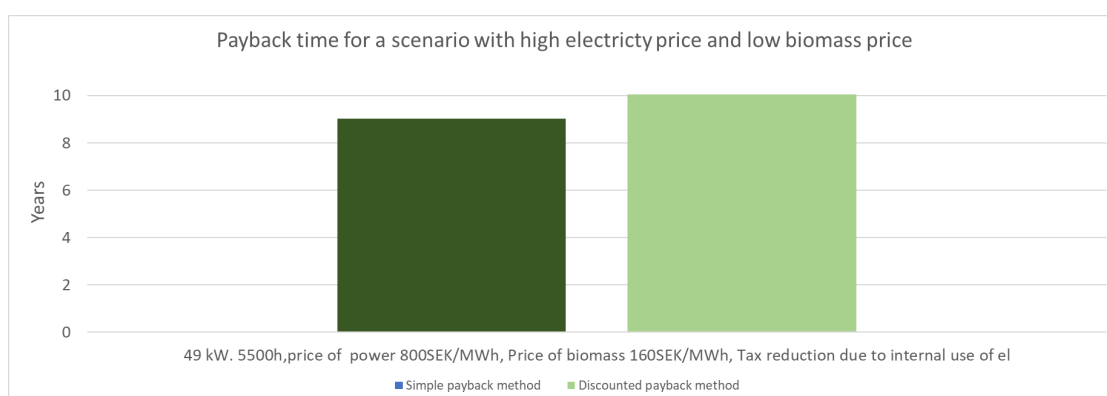


Figure 26. Payback time for a scenario with high electricity price and low biomass price.

10.1.2 Net annual profit

The net annual profit for the ORC installation in the studied base case is -97 498 SEK corresponding to -421 SEK/MWh.

To get profit out of the investment the net annual profit needs to be positive. Figure 27 shows the net annual profit when the operating hours for the base case is changed. To also illustrate the impact on the lifetime and discount rate, two different levels for the recovery factor has been used. Assuming a recovery factor of 0.1, which could represent an economic lifetime of 15 years and a discount rate of 6 %, the installation would be profitable at an operation time higher than 8000 h per year. If a recovery factor of 0.08 is used instead, which could represent an economic lifetime of 20 years and a recovery factor of 4 %, the installation would be profitable at an operation around 7000h per year.

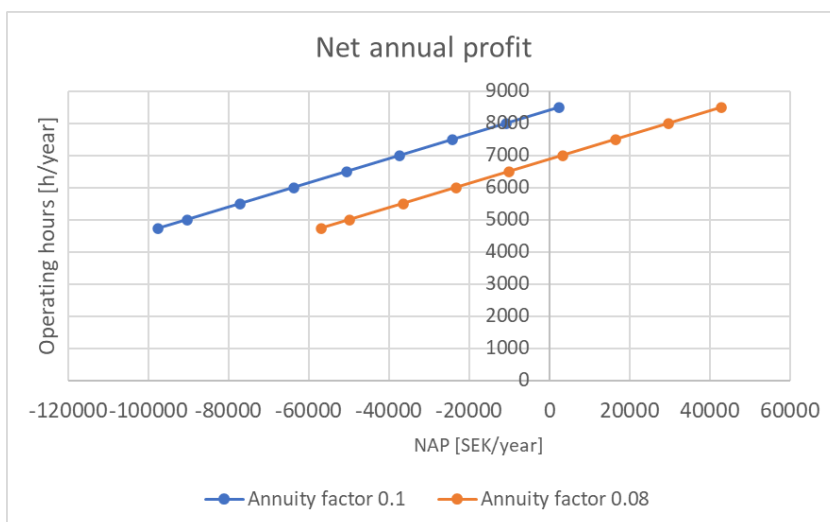


Figure 27. Net annual profit for the ORC installation, calculating with two different recovery factors.

As shown before, the price of electricity is another parameter that affects the profitability. Figure 28, shows at what price for the electricity the investment gets profitable. It is calculated for two recovery factors. As shown in the figure, the ORC investment with the conditions in the base case will have a positive NAP at a price of electricity above 700 SEK/MWh for a case with a long economic lifetime and a lower interest rate. For a higher recovery rate or shorter economic lifetime, the price of electricity must be over 900 SEK/MWh to get a positive NAP value.

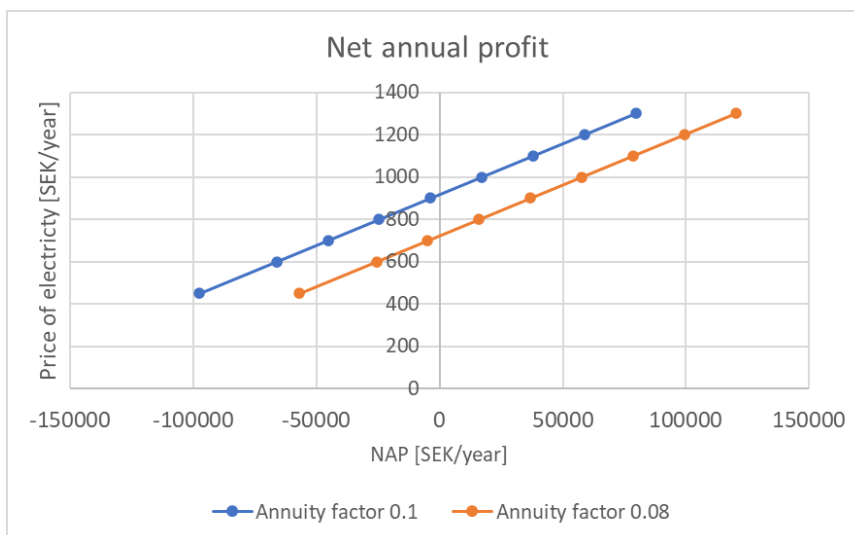


Figure 28. NAP for the ORC at different electricity prices and for two recovery factors.

10.2 Wet Steam Turbine

In this chapter, the payback time and NAP value is calculated for the WST unit. The price of electricity, annuity factor and running time are factors that significantly affects the profitability. These parameters are therefore evaluated in a sensitivity analysis.

Payback-time

The payback time for the WST varies between 17 and 84 years, with the input data in this study, see Figure 29. Scenario 5 shows no bar for the discounted payback method, which

means that the costs each year exceeds the income and savings and in that case the investment will never be paid back.

As can be seen in Figure 29, the result for the payback time will be significantly affected if discount rates are taken into account or not. The main reason is a high investment cost for the WST system, including rebuilding of existing plant. Except from the method used, the largest effect on the economics and the payback time is the possibility for tax-reduction or not. For a small WST unit it is therefore very important that the turbine is installed in the same company as the district heating production in order to be able to internally use the electricity that is produced and in order to (from a Swedish perspective) get tax reduction for the electricity used for electricity production. A higher price for electricity will significantly lower the payback (Scenario 1 and 2) time as well as a high price of biomass will significantly increase the payback time (Scenario 3).

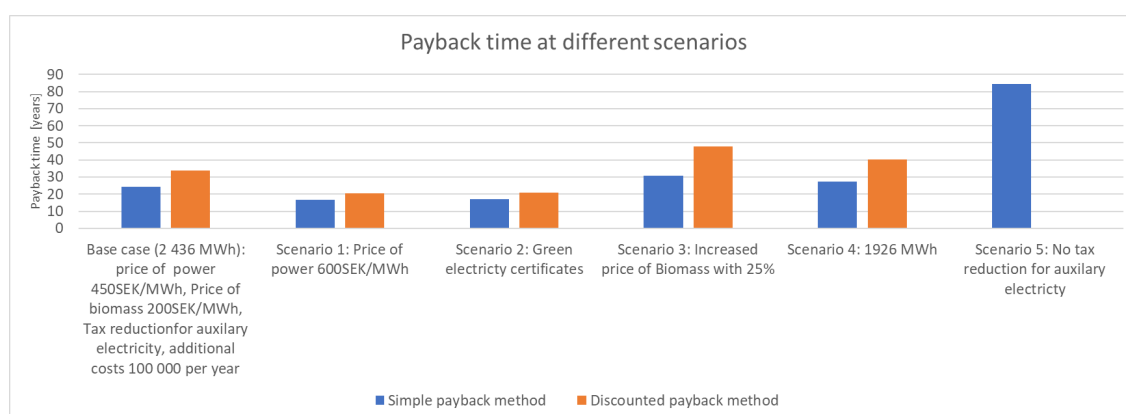


Figure 29. Payback time for a WST installation at different scenarios.

As shown above, the discount rate greatly affects the payback time. Figure 30 shows that the payback time varies significantly when changing the discount rate. For scenario 1, with a high electricity price, the payback time changes from 36 down to 18 years when the discount rate is changed from 5 % down to 1 %. For all scenarios, the costs exceed the income for a discount rate at 6 % and therefore no payback time is shown in the figure for that case. For the base case, the costs exceed the income also at a discount rate at 5 %, and for the scenario 3 both at a discount rate of 5 % and 4 %.

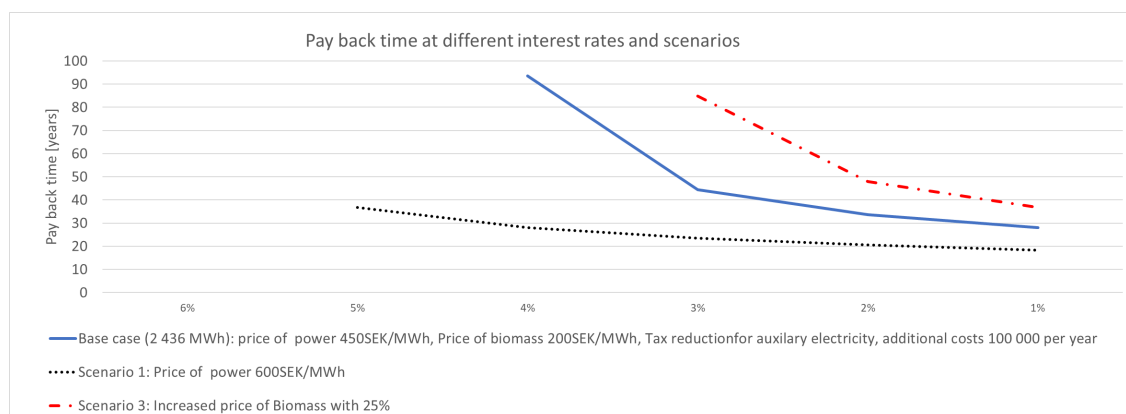


Figure 30. The payback time for the WST at different discount rates and for three of the scenarios.

Another parameter with great importance for the profitability is the number of operation hours, which is proportional to the electricity production. In Figure 31 the payback time is calculated for different discount rates and for different operating hours (4872h, 6000h and 8000h), at two different levels of electricity prices (450 SEK/MWh and 600 SEK/MWh). From the figure it can be shown that the payback time can be down to 13 years if the electricity price is high and the discount rate is low.

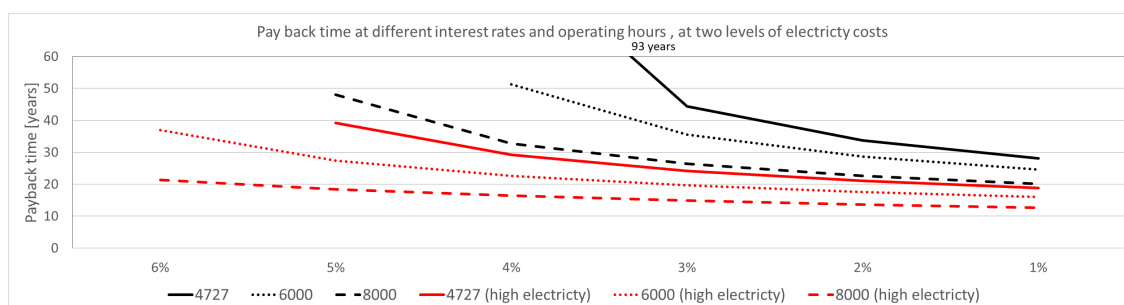


Figure 31. The payback time for the WST at different discount rates and operating hours at two different levels of electricity costs.

From the result the parameters that affects the payback time significantly is:

- The discount rates
- The tax reduction for electricity production
- The price of electricity
- The operation hours (electricity production)
- The price of biomass

The higher operating time that is possible, the more electricity can be generated, and the payback time will be lower.

The lowest payback time will be achieved with high electricity prices and low biomass prices. Figure 32, shows an example for a WST installation with the capacity of 500 kW, with operating hours from September to April (5500h). In this case the electricity price is 800 SEK/MWh and the biomass price is 160 SEK/MWh. The case could represent a future Swedish case with higher electricity price, or an increased power grid fee, but it could also represent a case in a country with higher electricity prices than in Sweden. If the tax reduction is added to the price of electricity, it could represent a case with an electricity price of around 1150SEK/MWh. The exact costs and revenues will vary from country to country and should be calculated for each case to get the exact prerequisites for the profitability.

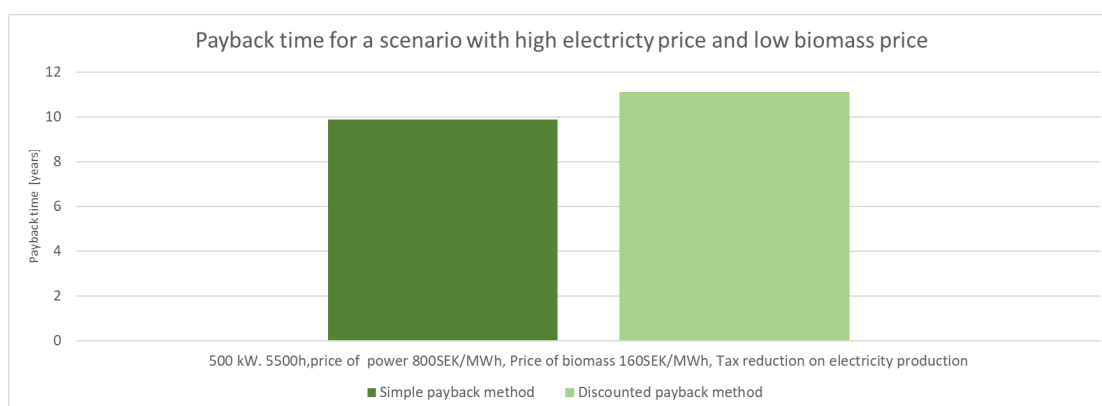


Figure 32. Payback time for a scenario with high electricity price and low biomass price.

10.2.1 Net annual profit

The net annual profit for the WST installation at the base case is -1 240 679 SEK corresponding to -509 SEK/MWh.

To get profit out of the investment the net annual profit needs to be positive. Figure 33 shows the net annual profit when the operating hours for the base case is changed. From the figure it can be concluded that with the input data for the base case, the income will not exceed the costs even if the turbine runs all year.

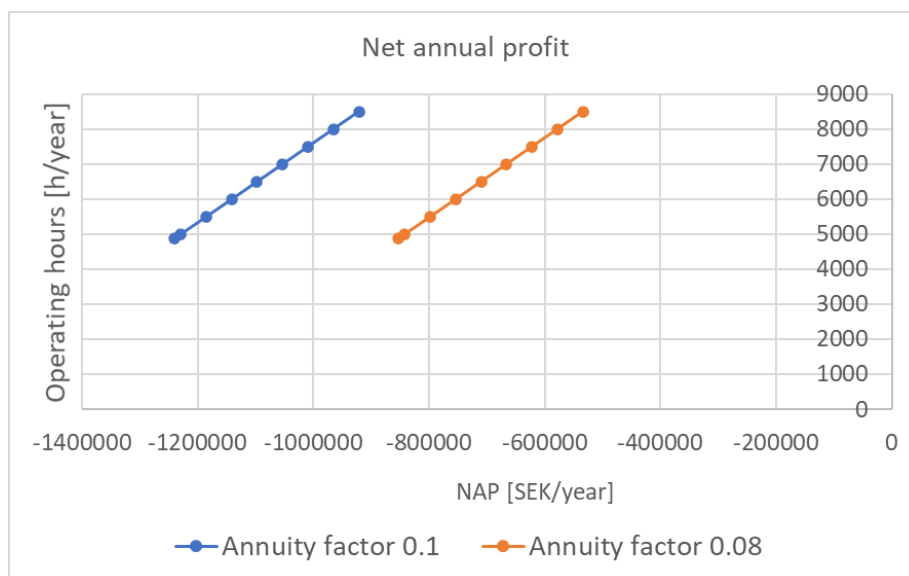


Figure 33. Net annual profit for the WST at different operating hours, and for two recovery factors.

To illustrate at which electricity price the income exceeds the costs, the NAP is calculated for the base case at different electricity prices and for two recovery factors. Figure 34 shows that the WST will get profitable at an electricity price above 800SEK/MWh when assuming a recovery factor of 0.08, and profitable at an electricity price of around 1000 SEK/MWh when assuming a recovery factor of 0.1.

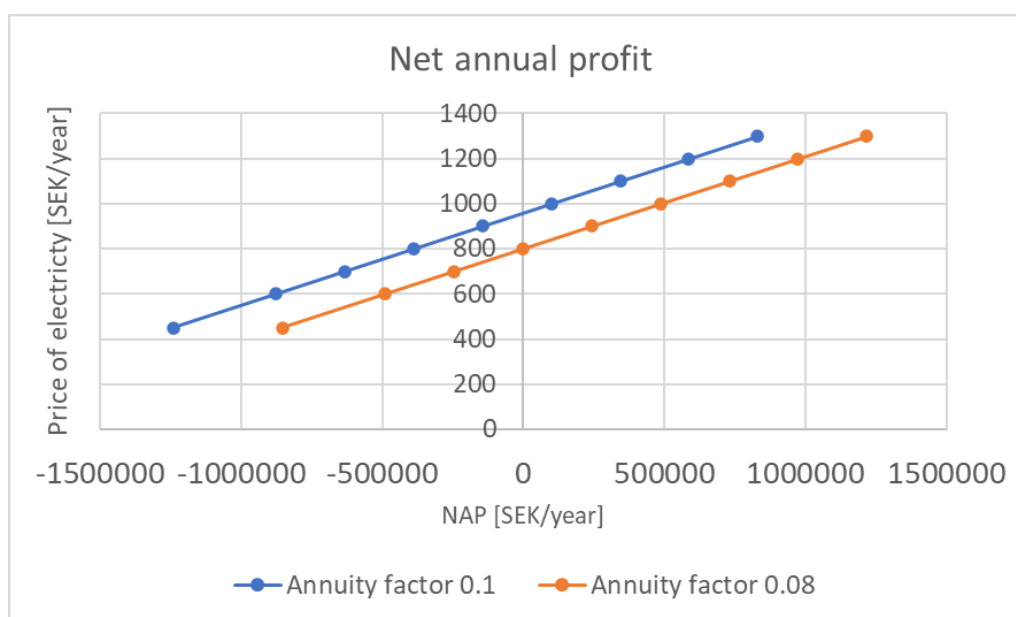


Figure 34. NAP for the WST at different electricity prices and for two different recovery factors.

10.3 Gasifier

In this chapter, the payback time and NAP value is calculated for the gasifier. The price of electricity, annuity factor and running time are factors that significantly affects the profitability. These parameters are therefore evaluated in a sensitivity analysis.

Scenario 5 without tax reduction described in Table 7 is not relevant for the gasification case, where the electricity production at full load only contribute marginally to the electricity demand at the dairy, i.e. maximum up to 15 % of the electricity demand. Instead, for the gasifier, Scenario 5 represents a case where no biochar is sold to the market.

10.3.1 Payback-time

The payback time for the gasifier varies between 10 and 12 years at the different scenarios, except from Scenario 4, see Figure 35. Scenario 4 represents the real operating hours of the gasifier during the demonstration at the dairy. In this case the payback time is negative, which means that the gasifier will never be repaid.

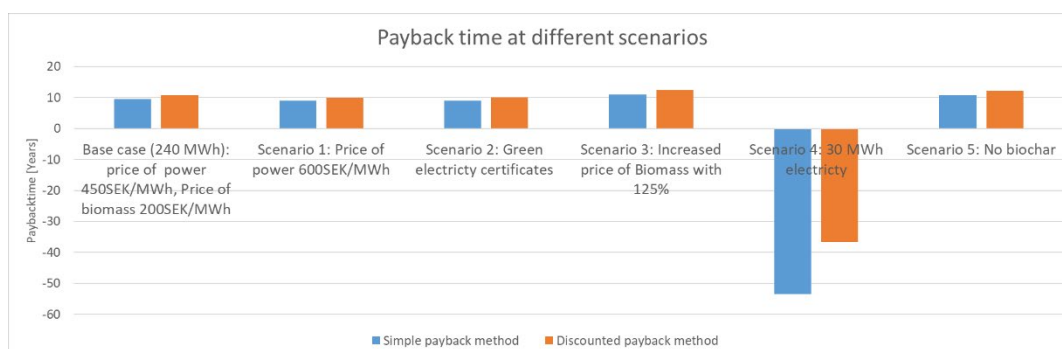


Figure 35. Payback time for the gasifier at various scenarios.

The discount rate is a factor that has a large impact on the economic calculations. Figure 36 shows that the payback time varies significantly when changing the discount rate. For scenario

1, with a high electricity price, the payback time changes from 13 down to 9 years when the discount rate is changed from 6 % down to 1 %. The payback calculations for the gasifier is less sensitive to changes in the discount rate compared to the other two technologies, which can be explained by that the gasifier has additional savings due to replacement of oil.

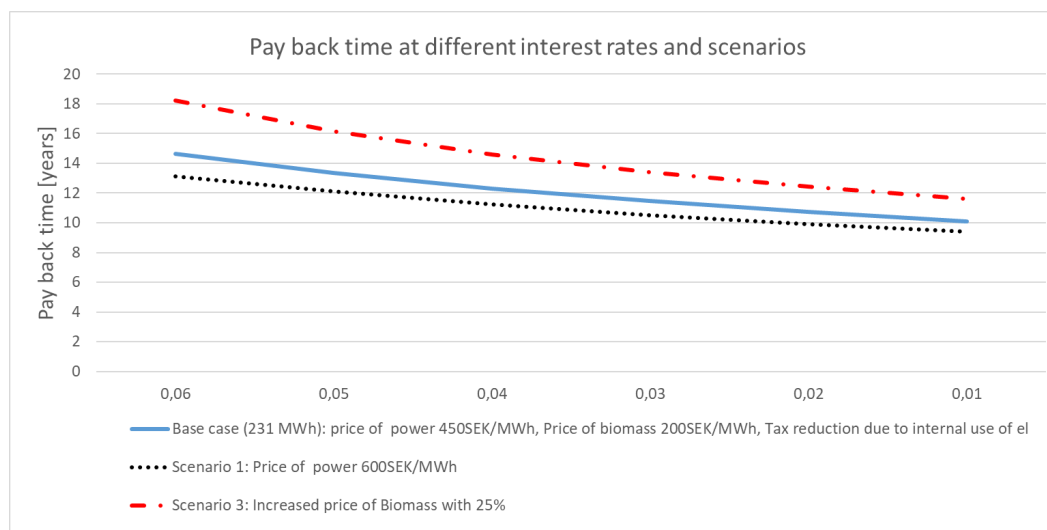


Figure 36 The payback time for the gasifier at different discount rates and for three of the scenarios.

From the result the parameters that affects the payback time significantly is:

- The discount rates
- The operation hours (electricity production)
- The price of biomass

The higher operating time that is possible, the more electricity can be generated, and the payback time will be lower.

The lowest payback time will be achieved with high electricity prices and low biomass prices. Figure 37, shows an example for a gasifier installation with the capacity of 40 kW_e, with 6000 operating hours. In this case the electricity price is 800 SEK/MWh and the biomass price is 160 SEK/MWh. The case could represent a future Swedish case with higher electricity price, or an increased power grid fee, but it could also represent a case in a country with higher electricity prices than in Sweden. If the tax reduction is added to the price of electricity, it could represent a case with an electricity price of around 1150SEK/MWh. The exact costs and revenues will vary from country to country and should be calculated for each case to get the exact prerequisites for the profitability.

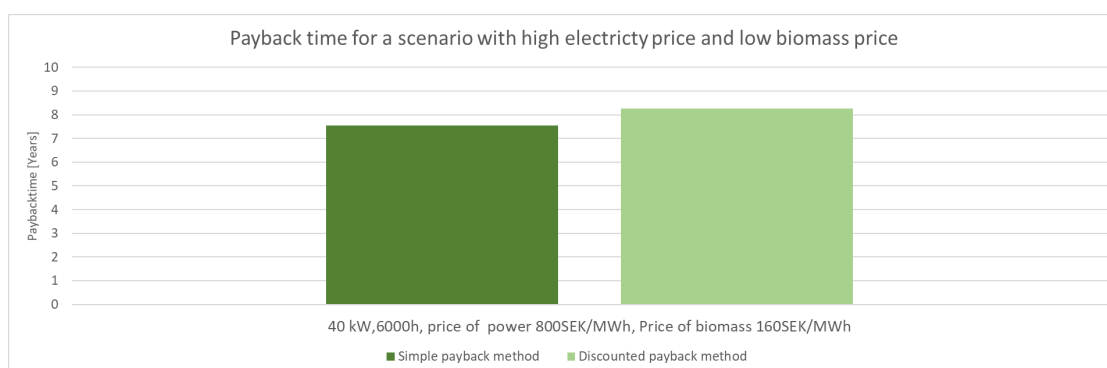


Figure 37. Payback time for a scenario with high electricity price and low biomass price.

10.3.2 Net annual profit

The net annual profit for the gasifier at the base case is 21 035 SEK and 87.6 SEK/MWh electricity.

The gasifier has a positive NAP for the base case. The operating hours was changed in the sensitivity analysis to find the minimum operating hours for a positive NAP. To also illustrate the impact on the lifetime and discount rate, two different levels for the recovery factor has been used. Assuming a recovery factor of 0.1, which could represent an economic lifetime of 15 years and 6 % the installation would be profitable at an operation time of around 6000 h per year. If a recovery factor of 0.08 is used instead, which could represent an economic lifetime of 20 years and a recovery factor of 4 %, the installation would be profitable at an operation time above 5000 h per year.

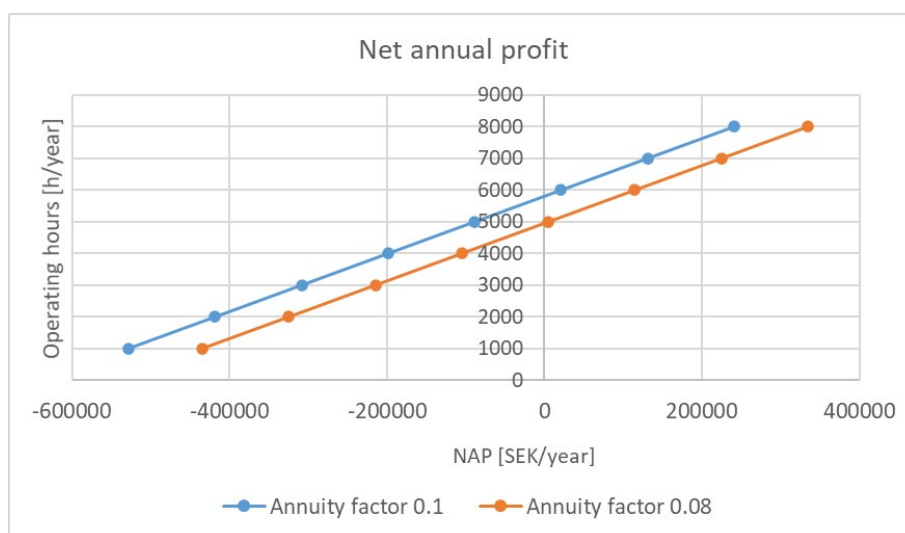


Figure 38. Net annual profit for the gasifier at different operating hours, and for two recovery factors.

To illustrate at which electricity price the income exceeds the costs, the NAP is calculated for the base case at different electricity prices and for two recovery factors. Figure 39 shows that the gasifier will get profitable at any electricity price when assuming a recovery factor of 0.08, and profitable at an electricity price of above 400 SEK/MWh when assuming a recovery factor of 0.1.

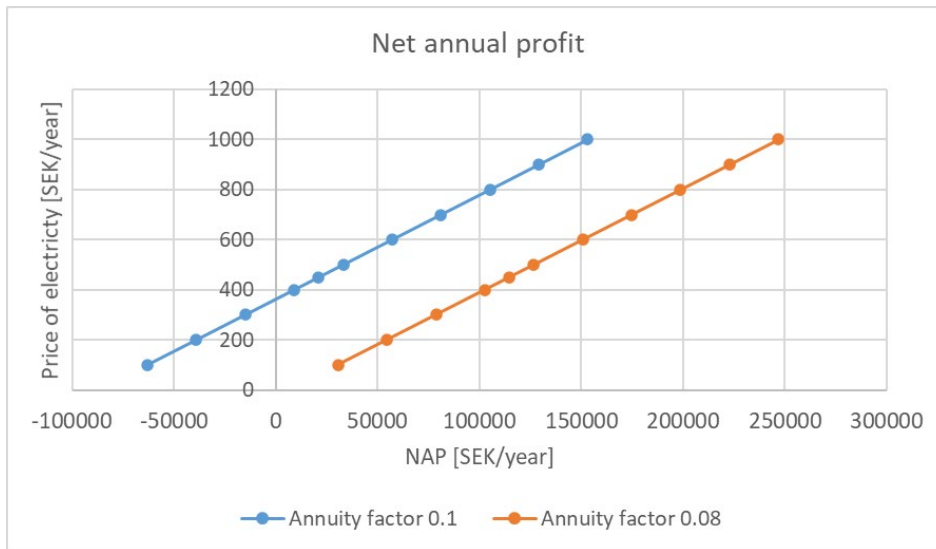


Figure 39. NAP for the gasifier at different electricity prices and for two different recovery factors.

11 Results - LCA analysis

The impact on the GHG emissions due to the small scale CHP technologies, ORC, WST and gasifier has been evaluated using the simplified LCA expanded approach which was described in Section 7.1.3. The combustion and gasifying of biomass do not contribute to a net increase in CO₂ in the atmosphere, unlike the combustion of fossil fuels, see also Section 2.1. The impact on the GHG emissions for the three technologies are therefore related to:

- + Increase of emissions due to increase harvesting of biomass
- + Increase of emissions due to increase transportation of biomass
- Decrease of emissions due to electricity savings on the market (the amount of emissions depends on the production of the electricity saved, therefore have four different scenario been used for the electricity generation, see also Section 8.1.
- Decrease of emission due to replacement of oil.

The ORC and the WST technology are installed in systems which already handle biomass and the GHG emission savings are therefore only related to the replacement of electricity produced on the market.

The gasification unit is installed in a system, in which an oil burner is replaced. The GHG emission savings are therefore related to both replacement of oil and electricity. The GHG emission savings will be lower if the gasifier is installed in a system where a biomass-based heating system is replaced.

11.1 ORC

The increase of GHG emissions due to an ORC installation is related to increased transportation and harvesting of biomass. The GHG emissions saved by an ORC installation is related to the saved electricity generation in the surrounded system. The amount of GHG emissions saved will depend on the generation of the saved electricity. The increase is small compared to the decrease and too small to be seen in Figure 40.

The results show, Figure 40, that depending on the source for electricity generation the GHG emission saved by an ORC installation of 49 kW with an electricity generation of 231 MWh/year varies between 3 to 310 ton CO_{2eq} per year.

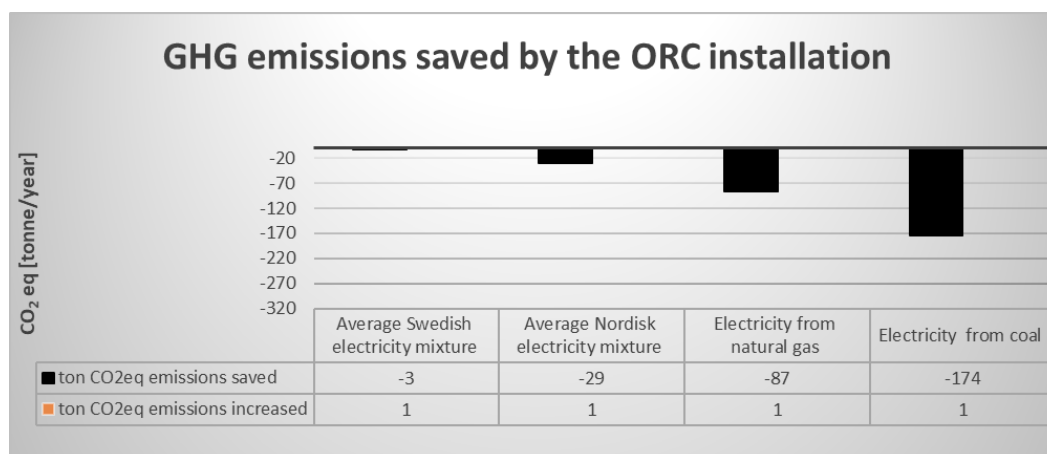


Figure 40. Saved GHG emissions due to power generation in an ORC unit with a total electricity generation of 231 MWh.

11.2 Wet Steam Turbine

Like the ORC system, a WST unit will increase the biomass demand and emissions due to transportation and harvesting of biomass will increase. The GHG emissions saved by a WST installation is related to the saved electricity generation in the surrounded system. The amount of GHG emissions saved will depend on the generation of the saved electricity. The increase is small compared to the decrease and too small to be seen in Figure 41.

The results show, Figure 41, that depending on the source for electricity generation the GHG emission saved by a WST installation of 500 kW with an electricity generation of 2.4 GWh/year varies between 19 and 1814 ton CO₂ per year.

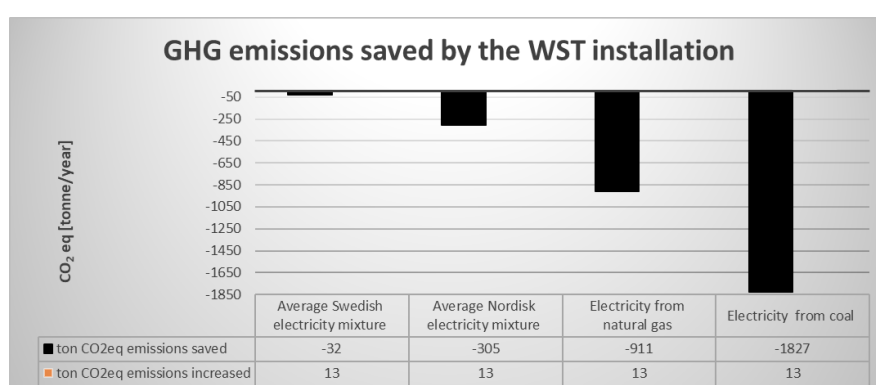


Figure 41. Saved GHG emissions due to power generation in an WSR unit with a total electricity generation of MWh.

11.3 Gasifier

The gasification process creates CO₂ emissions. However, these emissions are biogenic, and the net climate effect is thereby zero. The increased emissions due to the installation of the gasifier is GHG emission due to transportation of the wood chips needed and due to harvesting of the biomass. The GHG emissions saved by a gasifier is related to saved electricity and decreased oil demand due to heat generation in the gasifier, including less transportations with oil to the dairy. The increase is small compared to the decrease and too small to be seen in Figure 42.

The results show, Figure 42, that depending on the source for electricity generation the GHG emission saved by a gasification installation of 40kW with an electricity generation of 240 MWh/year varies between 219 to 398 ton CO₂ per year.

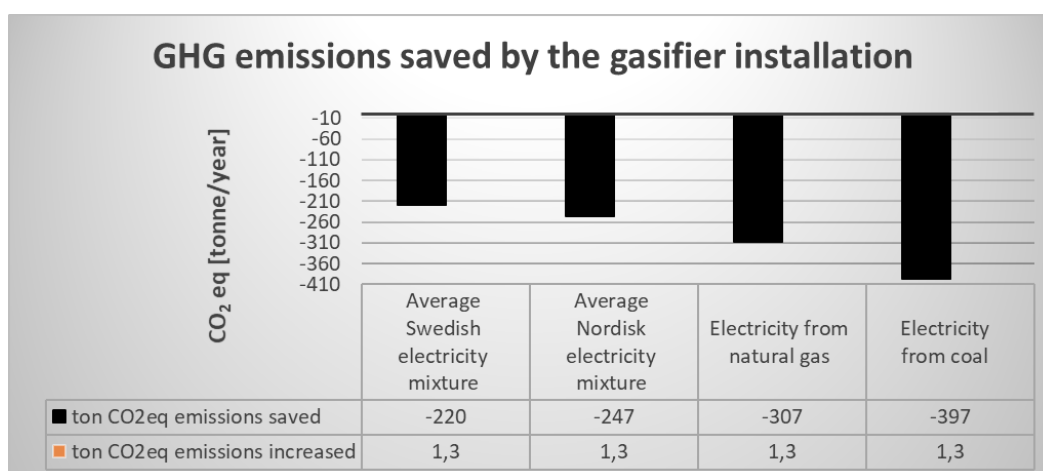


Figure 42. Saved GHG emissions due to installation of a gasifier.

12 Result – Socio-economic aspects

This Chapter presents the results from the socio-economic analyse. Focus is to describe the quantitative benefits and social aspects, defined in Section 7.

The pilot plant which the analyse is based on has only limited influences on social aspects. The largest environmental benefits are made if fossil fuels are replaced due to the installation of a small-scale CHP plant.

For all three studied technologies, the implementation will be a new experience for the company that buy it and further training is needed for the staff, to also handle electricity generation, and to handle biomass if the installation replaced fossil fuels. Formal training is necessary for the staff for all systems.

Several previous studies show that a biobased economy creates jobs. It is shown that biobased systems create more jobs compared to fossil fuel systems. Based on that knowledge, one part of this study is to evaluate the impact on working hours that is created in different parts of the projects.

12.1 New jobs

From the day the company decides to investigate the possibility for a small-scale CHP plant, it has an effect on working hours, both at the company itself and at consultant firms, suppliers of the technology and at many other companies that will be involved in the planning, construction and installation of the technology.

12.1.1 Jobs due to the ORC installation

Most jobs are created during installation of the ORC unit. The maintenance during operation is included in the daily supervision of the facility. The ORC installation has in total created 1055 working hours outside the district heating company, of which 790.5 hours are from local¹⁸ firms. The work has been limited between October 2016 until June 2017, 9 months.

Table 11 shows the result of the number of working hours created at different parts of the project. The project planning and design was partly made internally at the district heating company and together with the supplier. These hours are not seen in the table.

Table 11. Working hours created outside the company due to the ORC installation in BräkneHoby

Part of the project	Working hours	Local companies	National companies
Planning and design phase	89.5	1 (24.5h)	1 (65h)
Building and installation	957.5	3 (766h)	3 (191.5h)
Operation	Yearly service one day		1 (8h)

¹⁸ Located within Blekinge county

The installation of an ORC unit at the size of 49 kW electric at a district heating plant will not result in new job opportunities at the company. The unit need a daily check that takes about 15 minutes and the total work is estimated to 4-5 hours per months. That will be included and added to the tasks for existing staff.

The increase of biomass that is delivered to the district heating plant with a small-scale ORC unit, is marginal, and one plant will not increase the number of workers for transportation or harvesting the biomass.

In summary, during the planning and installation phase an ORC installation will create 1047 working hours during 9 months of which 75 % will benefit the local population. That is without the working hours created at the supplier of the ORC unit.

12.1.2 Jobs due to the WST installation

Most jobs are created during rebuilding and installation of the WST unit. The WST installation has in total created 7 060 working hours outside the district heating company, of which 61 % of the hours are from local¹⁹ firms. The work has been carried out from October 2014 until May 2019, 5 years and 8 months.

Table 12 Working hours created outside the company due to the WST installation in Ronneby

Part of the project	Working hours	Local companies	National companies
Planning and design phase	1 127	1 (29h)	3 (1 098h)
Building and installation	5 933	13 (4 265h)	8 (1 668h)
Operation	Yearly service one day		1 (8h)

Table 12 shows the result of the number of working hours created at different parts of the project. The project planning and design was partly made internally at the district heating company and together with the supplier. These hours are not seen in the table.

The working hours created at the supplier of the WST and at the supplier of the existing boiler, have not been possible to estimate based on the invoices. There are also invoices from construction companies that except costs for material includes cost for working hours, but the number of operating hours has not been possible to estimate from the invoices. The total amount of these invoices is 13.2 MSEK. Most of the costs are related to materials, but it includes working hours at the companies that has not been possible to estimate. The number of working hours created by the installation is therefore more than can be calculated based on the invoices.

The increase of biomass that is delivered to the district heating plant with a small-scale WST unit, is small, and one plant will not increase the number of workers for transportation or harvesting the biomass. However, if the demand for biomass increases that will create more jobs for both the harvesting and for the transportation of the biomass.

¹⁹ Located within Blekinge county

In summary, an installation of a WST in an existing district heating plant will require many working hours from local firms. During the planning, rebuilding and installation the WST installation has created 7060 working hours, of which 61 % benefit the local population.

12.1.3 Jobs due to the gasifier installation

As for the two other technologies most work is created in the building and installation phase of the gasifier. The maintenance during operation is included in the daily supervision of the facility, however, for the gasifier to work properly a dedicated service person is needed.

The gasifier at the dairy has created 1241 working hours outside the dairy, of which 1058 hours has been in local firms. The installation has created 962 working hours during almost two years.

Table 13 shows the result of the number of working hours created at different parts of the project.

Table 13. Working hours created outside the company due to the gasifier installation in Hulstfred

Part of the project	Working hours	Local companies	National companies	EU company
Planning and design phase	279	1 (279)		
Building and installation	963	6 (780)		1 (183) ²⁰
Operation	Yearly service one day			1

The installation of a gasifier at the size of 40 kW electric will not result in new job opportunities at the company. The unit need a daily check that will take about 30 minutes but needs also regular service. The experience from the pilot plant in Hulstfred and from taking to other suppliers are that to get a gasifier running satisfactory, a dedicated service person is needed. However, for the supplier to be able to hold such a person, around 10 gasifiers are needed within a reasonable area.

The increase of biomass that is delivered to the gasifier will create working hours for transportation. However, the amount of biomass and deliveries to the gasifier in Hulstfred are too few to create new job opportunities, but when the gasifier technology is spread it will require more jobs in transportation and harvesting firms.

In summary, during the planning and installation phase, a gasification unit will create around 1242 working hours for two years, of which 83 % benefit the local population. However, when the gasification technology is spread that will create more jobs both in the harvesting and transportation of the fuel but also for service and maintenance of the gasifiers. The working hours does not include the work created at the supplier of the gasifier.

12.1.4 Job creation – compared to previous studies

An increase use of bioenergy is shown in the literature to increase local jobs, both indirect and direct jobs. The number of direct and indirect jobs created depends on the project and country

²⁰ The working hours was not written on the invoice and the numbers are therefore estimated based on the final invoice amount.

and it could be hard to generalize. In a summary conducted by IEA in 2003, a biomass use of between 2 and 40 MW_{th} could create between 65 and 115 jobs (both indirect and direct jobs). The Swedish biomass association estimate that a use of 1TWh (1 000 000 MWh) biomass will create 400 jobs (300 direct and 100 indirect)²¹. The three demonstration plants use 272 MWh, 3248 MWh and 828 MWh biomass, and created 0.72, 0.71 and 0.3 jobs during the planning and construction phase for each technology. The created working hours for the WST was the highest but was also the installation that took the longest. The installation of the ORC and the gasifier had around the same number of working hours, but the time for the ORC installation was shorter, which result in a higher share of a full-time work. If the results of jobs are scaled up to 1TWh of biomass that would result in 2647 jobs for the ORC technology, 219 jobs for the WST technology and 362 jobs for the gasification technology. However, the numbers of jobs created by ORC installations of 1TWh biomass is very high and perhaps not realistic. However, the scaling indicate that an increase use of small-scale CHP installations creates local jobs and as stated in the Forest strategy of Småland, is very important for the economic growth in the region of south east Sweden.

To get the exact number a more detailed analysis is needed.

12.2 *Security of supply*

One of the most important aspects of a small-scale CHP installation based on biomass is the increase of security of supply.

First, biomass is a local fuel, and an increase of biomass use will affect the local economy. If the electricity is used internally at the company it will decrease the need and costs for electricity and will not be affected if the price of electricity goes up.

Second, the electricity generated in a small-scaled CHP installation is weather independent during the winter when the power demand is the highest. That means that even if the electricity is produced and used within one company, it will unburden the power grid. Lack of capacity in the power grid is an increasing problem in Sweden and every measure that can unburden the power grid is important. A small-scale CHP unit will unburden the power grid when the need of power is the highest and is therefore a very important measure in the local power grid. There are also examples in Sweden where all the capacity in the grid are taken, which affects companies that needs more power to be able to expand. If that company is a district heating company, a solution could be to install an ORC to generate electricity to be able to expand the heat production.

Third, with a small-scaled CHP unit installed at a company or a district heating plant there are a possibility to be able to delivery heat even if the power on the grid is out. That will increase the security of supply of energy to the sociality or secure the production at the company. The CHP unit, however, needs energy from the boiler to start, and if the power is out the system is in need of a diesel (or HVO) generator to produce electricity for starting the district heating plant before the ORC can take over.

Fourth, the electricity generated from a biomass-based small-scale CHP is both local and renewable and will increase the local renewable electricity generation.

Fifth, a small-scale CHP plant could in the future offer system services such as steering of frequency and voltages on the power grid.

²¹ Discussion with Gustav Melin 2020-10-09

12.3 *Impact on local economy*

Focus on the local society has increased during the last years, because of a more unreliable and uncertain world. Several regions in Sweden have introduced goals to be net energy producers in 2050 (all energy forms included).

A small-scale CHP unit will increase the local electricity generation. The generation will be small but will play an important role in the local power grid, when the pressure on power capacity is increasing.

12.4 *Health and safety*

Small-scale CHP units will increase the combustion of biomass, however, if the combustion take place in an already existing boiler, the emissions will go through the existing cleaning system. Necessary cleaning of the flue gases is depending on the size of the boiler. A new installation, as a new gasifier will also emit flue gases due to the gasification of the biomass. The necessary flue gas treatment will depend on the size of the gasifier. The gasifier size in this report does not require any treatment of the flue gases.

Some oil and nitrogen leak from the ORC unit. However, the oil is captured in the system and returned. Some nitrogen will leak to the air but is not dangerous. The refrigerant in the ORC cycle has a very low GWP value – which makes it not dangerous for the environment and it is not dangerous for human.

The WST operates under high pressure, which increases the risks in the process. The turbine also contains moving parts that spin at very high speeds, which can cause major damage if broken during operation. However, all employees have undergone education for steam and high pressure to manage the new system.

A leakage in a gasification system could result in a high concentration of CO, which is very toxic. However, the gasification system has an alarm system that warn if the CO concentration goes up.

The noise level is within required levels and the safety for technicians will not be affected by an ORC installation or a gasification installation of 49kWe and 40kWe. However, a WST installation of 500 kW needs to be isolated from noise in order to be within the required noise levels.

13 New installations and potential

This Chapter describes the development of small-scale CHP the last five years.

13.1 *Status of small-scale CHP today, 2020*

Since the beginning of the *Life+ project, Small scale CHP*, in 2014, several new suppliers for small-scale CHP has entered the market. Installations of gasifiers and ORC units have increased especially in countries with favourable incentives and political support, such as UK, Germany, Austria, and France. Several new installations have also been installed in Sweden and Norway as a direct result of the Life+ project, *Small scale CHP*.

The numbers of small-scale gasifiers have increased during last years and new suppliers are available on the market. For example, Burkhardt is one company that today²² have around 30 wood gasifiers installed mainly in municipality heating networks and farms. Most units in Germany, UK and Italy but also a few in Japan, Austria and Slovenia. Glock Ökoenergie is another company that was established in 2010, released their pilot plant in 2015, and had (in January 2019) 32 plants in operation. The company Froling has worked more than 50 years with wood and heat. Since 2014, they also offer biomass gasification solutions with an electrical capacity of 46-56 kW and (as of January 2020) they have 140 gasification units installed mainly in Austria.

The numbers of ORC units have also increased with new units and new suppliers the last five years. A thorough overview of the world Organic Rankine cycle market was published in 2017 (Tartière & Astolfi, 2017). The overview shows that the market leader (up to 31 December 2016) was the American company ORMAT, with 62.9 % of the total installed capacity, followed by the Italian companies Turboden (13.4 %) and Exergy (11.1 %). 23 of the listed companies have focus on small and medium applications, and they share 3.2 % of the market. It also shows that the power generation from geothermal brines is the main field of application for all ORC capacity installed, with 74.8 % of total capacity. However, the number of plants is relatively low since these plants are large scale-installations with several MW. The authors describe waste heat recovery as an emerging field for ORC with interesting potential for all sizes of ORC facilities. The big players are active in the area with medium-large installations. However, most of the other companies focus on small scale waste heat recovery applications with production of electricity ranging from 10 to 150kW_e. Waste heat recovery cover 13.9 % of the market. ORC units in biomass applications present around 11 % with considerable number of plants. ORC applications based on biomass has largely been driven by financial incentives in central Europe that have been favourable to 1 MW plants (Tartière & Astolfi., 2017).

Two suppliers on the European market that has increased their installations the last five years are Enogia²³ and Rank. Enogia deliver ORC units from 10 kW_e to 180 kW_e. Enogia has around 50 references²⁴ globally, of which 20 are installed in France in mainly biogas applications, and 10 are installed in UK in biomass applications. The other references are one or two installations

²² October 2020

²³ <http://enogia.com>

²⁴ <http://enogia.com/wp/>

in several countries globally. Rank deliver ORC units from 2.5kWe up to 115 kWe. Rank has around 19²⁵ references in Europe, of which 10 are installed in Spain and 5 in UK.

Two Swedish companies that has increased on the European market, not listed in the overview by Tartieé & Astolfi, are Againty²⁶ and Climeon. Againty has since 2016 delivered 18 ORC units from 20 to 450 kW_e in Sweden and Norway. The main application has been in the district heating network (CHP). Climeon²⁷ has since the first installation for waste heat recovery at an industry in Sweden installed several units in UK and lately for geothermal applications and in marine applications.

Only two new small wet steam installations, to Schweiz and the Netherlands, are found during the last years. It has been hard to find information, which mean that it could be installations that are not known for the authors of this report.

13.2 *New installations as a direct consequence of the Life project: Small Scale CHP*

The main aim for this demonstration project has been to disseminate the possibility for small-scale CHP to pave the way for a broader market introduction and use of the technologies.

The supplier of the ORC plant has shown that their technology has a high availability and have sold over 15 ORC units thanks to the demonstration plant in BräkneHoby. Figure 43, shows the locations of the installations in Sweden and Norway. These units have a total capacity between 2,5 and 3 MW, and a possible electricity generation of between 12.5 and 15 GWh²⁸ each year.



Figure 43. ORC units in Sweden and Norway that is a result of this demonstration project.

No other WST or gasification units have been installed in Sweden during the project period. The supplier of the WST has during the project sold two WST units for customers in EU. Both units are 500 kW and were delivered to Netherlands and Schweiz in 2018.

²⁵ <https://www.rank-orc.com/case-histories/>

²⁶ <https://againity.com/>

²⁷ <https://climeon.com/>

²⁸ Assuming an average operating time of 5000 h per year.

The demonstrated gasifier was one of the first from the supplier, and additional modified to a prototype. Today, the supplier has over 100 gasifiers sold, most of them in the UK.

Back in 2014, there were mainly two suppliers of gasifiers on the market. Today there are several more companies that provides gasifiers in the same scale as in Hultsfred. However, the main development occurs so far in mid-Europe where the price of electricity and incentives for biomass use is more favourable.

13.2.1 Arguments and Payback times for new installations

It is mainly the ORC technology that has been spread to district heating companies in Sweden and Norway. The ORC units that has been installed after the pilot plant in BräkneHoby are between 50 kW_e and up to 450_e kW. The main arguments put forward by the companies as reasons for their investments are:

- Profitable (Reasonable payback time)
- Environmental reasons (decrease the share of bought electricity)
- Lack of power capacity (to unburden the power grid)

All the companies that answered our short survey mention that the main reason is a reasonable profitability along with environmental reasons to decrease the need of bought electricity. Several of the companies are in regions with possible lack of power capacity on the power grid and highlight also that issue as an argument for the investment. One of a few of the companies also mentioned available excess heat, available excess raw material and to take part of the product development as reasons for the investment.

The considered payback time for the investments varies between 5 and 11 years. All installations of small scaled ORC units based on biomass that has been installed in Sweden after the pilot plant in BräkneHoby are listed in Table 14.

Table 14. ORC installation at district heating plants installed after the pilot plant in BräkneHoby.

Place	Energy company	Installation year	Installed capacity	Considered payback time
Hörby	Solör Bioenergi	okt-18	50	8
Örkelljunga	Örkelljunga fjärrvärme	nov-18	200	7-8
Töreboda	Väner Energi	apr-19	50	11
Moheda	Alvesta Energi	jun-19	50	8
Högsby	Högsby Energi	okt-19	50	No information
Elverum		Dec-19	450	No information
Perstorp	Perstorp Energi	jan-20	315	8
Vilhelmina	Solör Bioenergi	June- 20	50	No information
Svenljunga	Solör Bioenergi	Sept- 20	315	5
Finspång	Finspång Tekniska Verk AB	Nov-20	450	5

Ystad	Ystad Energi	Jan – 21	250 x 3	No information
Västervik	Västervik Energi och Miljö	2021	90	No information

13.3 Potential for small scale CHP in south east Sweden

Bioenergy use is important in south east Sweden. Bioenergy is mainly used to meet the energy needs for heat and electricity, only a small amount of biofuel is used for vehicle production in the region. In this region, biofuel accounts for 50 % of the total supplied energy). The use of biofuel consists mostly of Black liquor used in the two pulp mills and wood fuel for mainly district heating production. The bioenergy use is greater than the average bioenergy use in Sweden. The underlying reason is the large forest resources, the active forestry in the region, two large pulp mills and a well-developed district heating network, both in central cities and in smaller urban areas. The district heating network mainly consist of many small networks with heat only production.

South east Sweden was the first region in Sweden to apply a regional Forest Strategy.

Based on this, the conditions for small scale CHP installations based on biomass is very good in south east Sweden.

13.3.1 Small scale CHP at district heating companies

To estimate the potential for small scale CHP in south east Sweden all boilers for district heating or local networks have been identified. We have assumed that the possible technologies are either an ORC or a wet steam. It is also assumed that boilers under 2 MW are too small for these technologies; therefore, these boilers have been excluded in the analysis.

The investigation shows that there are 41 boilers larger than 2 MW in southeast Sweden, excluding the largest boilers which already have electricity generation and back-up only boilers. These 41 boilers produce around one third of the heat delivery in the district heating systems in the region.



Figure 44. South east Sweden

The potential for electricity production has been estimated based on calculations used in (Oscarsson 2017):

- Electricity is produced only during winter
- 80 % of the produced heat is assumed to occur during winter

- 8 % of the heat can be converted to electricity

The potential for electricity generation from ORC units in south east Sweden are 51 GWh electricity per year, which corresponds to 0.8 % of the electricity demand in the region. Oscarsson (2017) estimate the potential for small scale CHP to be between 296 and 567 GWh in Sweden, which should correspond to about 0.2 to 0.35 % of the total Swedish electricity demand in 2019.

The potential electricity production corresponds to between 2 to 38 kton GHG emission savings each year, depending on the electricity generation saved.

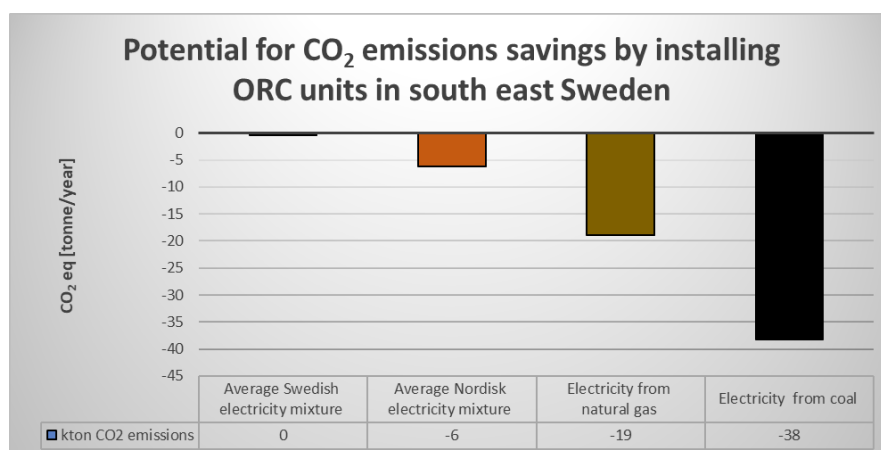


Figure 45. Potential for GHG emission savings by installing small scale units in south east Sweden.

13.3.2 Small Scale CHP in the sawmill industry

There are 24 sawmills in south east Sweden with a production higher than 20 000m³ sawn timber (Svenskt trätekniskt forum, 2018). There are many sawmills, but none of the largest are in the region. Sawmills are both user and a supplier of biofuels. That the sawmills are discussed as interesting for electricity production and especially for small scale CHP is mainly due to the following:

- When producing timber, approximately 250 kWh of heat per m³ is needed for drying sawn timber. There is thus a heating base that enables simultaneous electricity production (Oscarsson 2017).
- The production of sawn wood is an electricity-intensive production
- Heat production takes place for most of the year and around the clock, which can provide benefits for the profitability of small-scale CHP.

The potential for small scale CHP based on biomass in the sawmill industry was evaluated in a study by Johansson (2019). In that study, the result showed that the electricity potential for the ORC technology in the sawmill industry in south east Sweden was around 800 MWh electricity. The potential for the ORC technology depends on the availability of a cold stream around 40-50 °C, e.g. a return stream from the district heating network. The result shows that only two of the interviewed companies deliver district heating to a nearby community.

13.3.3 Replace fossil oil use by gasifiers

There is still some fossil oil use left in industries, farms, and companies in South east Sweden. Based on statistic from the county administrative board, the oil use in the industry, at farms,

forestry and fishing was in 2017 around 600 GWh. Part of that oil use is for transportation and could not be exchanged with small scale CHP installations. However, a large part is most likely used for heat generation in processes and buildings.

If an oil demand of 600GWh is replaced with biomass gasifiers, additional 216 GWh of electricity could be generated in south east Sweden.

13.4 *Potential for small scale CHPs in EU*

The development of small-scale CHP technologies has so far been greatest in EU countries with high incentives for electricity generation from biomass, in UK, Germany and in Austria.

Based on the experience in this study, the potential of a continued development of small-scale CHPs in EU will mainly depend on two factors:

1. The electricity prices (or feed-in tariffs or other subsidies)
2. Existing heat demand – in district heating networks or industries/buildings

Local incentives will also affect the profitability, potential and development of small-scale CHPs. The highest potential is not necessary depending on a local supply on biofuel. But it might affect the local incentives to use local biofuels. France and Germany have introduced a price on CO₂ emissions, which create incentives to increase the biomass use in these countries.

The countries with the largest total forest biomass potentials per unit of land can be found in northern Europe (southern Finland and Sweden, Estonia and Latvia), Central Europe (Austria, Czech Republic and southern Germany), Slovenia, southwest France and Portugal (Verker et al. 2019).

The district heating networks has been mapped by Persson et al. (2014), see also Figure 46. The countries with most district heating networks are Denmark, England, Poland, Czech Republic, Austria, Netherlands, Slovenia, Parts of Germany and France as well as the Baltic countries (Latvia, Estonia and Lithuania).

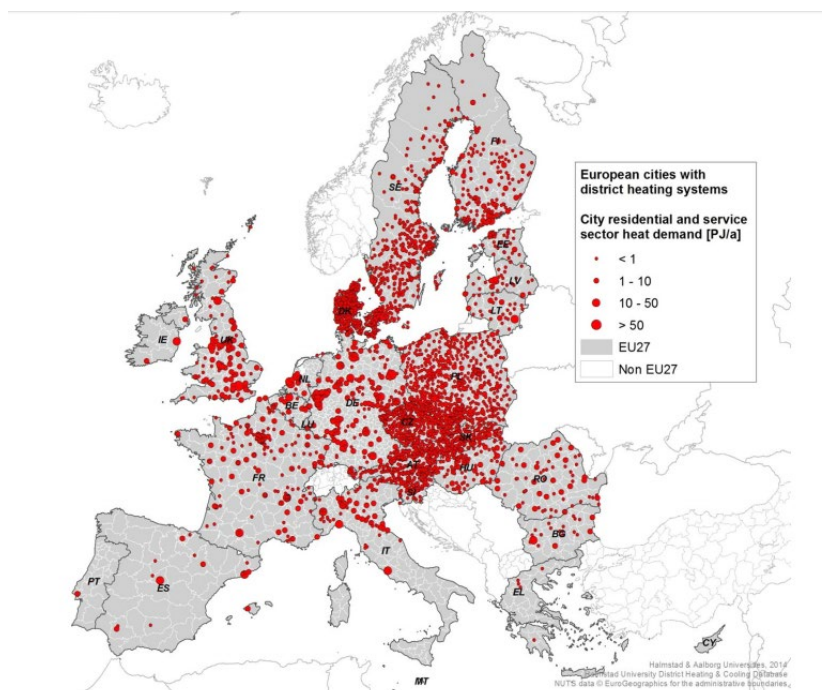


Figure 46. European cities with district heating systems. Sources: U. Persson et al. / *Energy Policy* 74 (2014) 663–681

The potential for small-scale CHP is large in EU, but the potential is larger in countries that have beneficial electricity prices, that have available infrastructure (e.g. district heating networks) and the incentives to use biomass is often higher in countries with available biomass. Some countries that have all these three factors are: Germany, Slovenia and Austria. But the result in this study shows that small scale CHP from biomass could be reasonable profitable even in countries like Sweden and Finland with the lowest electricity prices in EU.

14 Conclusion and discussion

The development of small-scale CHP from biomass relates to five of the global goals for a sustainable development.

Installing a small-scale CHP using biproduct from forestry will generate local renewable electricity, when the electricity demand is the highest, during winter. That will lead to the development of sustainable cities and a robust infrastructure for electricity. It also creates new jobs, during building, planning and installation. The growth of small-scale CHP will contribute to the increase of renewable electricity and the decrease of fossil CO₂ emission.



Figure 47. Goal 7,8,9,11, and 13 are the goals of the 17th global goals that will be considered when installing a small-scale CHP unit in Sweden.

14.1 Economics

The result in this study shows that small scale CHP from biomass could be repaid within a reasonable payback time, under right circumstances. The payback time is significantly affected by:

- The tax relief (In Swedish context: below 50kW_e)
- The price of electricity (Price of sold electricity, price for incoming electricity, power grid charges etc.)
- The discount rates
- The operation hours (electricity production)
- Price of biomass

All these parameters are country, company, and site specific. The price of biomass for example can vary very much depending on the type of biomass and local agreement between supplier and byer. It is for example more expensive to use refined biomass, such as pellets, and a higher electricity price would be necessary to gain a reasonable payback time for a small-scale CHP plant with that fuel. The electricity price is also depending on agreement between the power grid owner and the company. The price of sold electricity is often cheaper than the price of bought electricity. There is also a power grid charge and additional charges from the power grid owner for the electricity capacity guaranteed to the company.

Most money is saved if a company, i.e. a district heating company, could install a small CHP unit that produce more power than is needed for the company itself, so that the company become a net exporter of electricity.

However, if the maximum possible capacity that could be installed is below 100 kW²⁹, then the tax reduction significantly affects the profitability. In that case all electricity needs to be used within the company to gain highest profitability. Today the tax-level for energy tax is above 50 kW_e. However, it is a proposal that is being considered where the proposal is to raise the tax limit to 100 kW_e. If the tax limit is raised there is a potential for CHP units in systems that today are limited by the tax level to increase the capacity and the profitability of the unit.

Investments made after the pilot facilities in this project have shown calculations with payback times between 7 and 8 years, for a small-scale ORC unit. An installation of an ORC is often compared with installation of solar power. In the cases where a comparison with solar power has been made, it is in all cases shown that the payback time for an ORC unit is more profitable. The electricity from a small-scale CHP unit is also produced when the need of power is the highest, and hence for most cases, when the price of power is the highest. For example, for a district heating plant to become completely self-sufficient on electricity, the best solution is to have an ORC that produces electricity from September to May and solar cells that produce electricity in the summer.

An installation of a small-scale CHP that replaces fossil oil, is less sensitive for changes of above-mentioned parameters, which depend on the income that is saved by less need of oil.

14.2 *Environmental assessment*

The environmental benefits from installing a small-scale CHP unit will depend on:

- The amount of electricity generated
- The GHG emissions generated in the power production that is being saved by the small-scale CHP unit
- If the installation of a small-scale CHP unit also leads to a change of fuel from fossil to renewable (Biomass)

The largest GHG emission reduction will be obtained with the largest electricity generation, in this report by the WST installation. But the amount of GHG emission saved will depend on the production of the electricity saved. In a Swedish perspective the largest reduction represents the electricity generated in winter, during times when electricity is imported. For both the ORC and the WST case the GHG emission saved would be larger than the numbers for the Swedish average electricity generation. The reason is that the electricity from these units will be produced during the time of year when the electricity demand is the highest and when the import of electricity is the highest. The GHG emissions saved will be larger if the installation takes place in countries where the saved electricity generation is from coal or natural gas.

The reason why the gasification system shows a larger reduction in GHG emission compared to the ORC system is that the reference case in which the gasifier is installed produce heat via an oil boiler, while the reference case for the ORC is based on biomass and the heat generation

²⁹ The limit is 50 kW in Sweden today, but the tax-limit is most probably raised to 100 kW within a soon future.

is already CO₂ neutral and hence, the heat generation from the ORC unit will not change the heat generation. If a gasifier instead is installed in a system where it replaces a pellet boiler, the GHG emissions saving would be similar to the savings from the ORC unit with the similar electricity production.

14.3 *Socio-economic parameters*

The installation of small-scale CHP units in Sweden will contribute to the local economy. Local firms will be used in the planning and construction phase. The running of the unit will not create new jobs, but when the number of units increases the need of biomass will increase and that will increase the need of jobs in the forestry, the need of drivers and the need of workers at the supplier of the technology. Suppliers of small-scale CHP units are located in EU and sustainable biomass is available in EU.

The development of small-scale CHP units in EU, which currently is happen, will therefore contribute to both local renewable electricity generation, local jobs, and jobs within EU. Installing small scale CHP unit will also increase the efficiency of heating plants, increase the power produced from renewable resources which leads to a reduction of fossil CO₂ emissions.

Small scale CHP solutions will contribute to the security of supply, not only for the company itself, but also for the local society by:

- If the electricity is used internally at the company it will decrease the need and costs for electricity and secure the company for high variations of the electricity price.
- A company that is self-sufficient of electricity will not be affected if the electricity on the grid disappears
- A small-scale CHP unit will unburden the power grid when the need of power is the highest and is therefore a very important measure in the local power grid.
- The electricity generated from a biomass-based small-scale CHP is both local and renewable and will increase the local renewable electricity generation.
- A small-scale CHP plant could in the future offer system services such as steering of frequency and voltages on the power grid, if needed and in general act as an important contributor of electricity in the increasingly complex system of self-consumption.

In general, small scale CHP installations have not a large impact on health and safety issues. All regulations and laws that concerns noise and emissions must be followed and sometimes measures are needed to be able to reach the granted levels. For example, in this study the noise levels for the ORC and the gasifier where within the granted levels while the WST installation needed an isolated turbine room in order to be able to reach the noise levels in the district heating plant. Another example is that combustion or gasification of biomass needs to follow the regulations needed for the concerned size of investment. For the size of the gasifier in this project, no extra cleaning of the flue gases were needed and for the WST and ORC units, these were installed in district heating plants which already fulfil all requirements for the flue gases due to combustion of biomass.

The biomass used for the small-scale CHP units must also be sustainable. But as long as biomass considered as by-products are used, which is the case for the sustainable forestry in EU, biomass is a renewable and sustainable alternative for power generation.

14.4 *Small scale CHP potential*

The potential for small scale CHP is considerable, especially in the local perspective. The potential for small scale CHP is highest in countries and areas with large heat demands, either in the district heating system or in industries. The district heating system is already well developed in parts of Europe. The technology with highest potential for district heating plants are ORC units or if the boilers are larger, steam turbines or Wet Steam Turbines.

The countries with favourable electricity prices or incentives for using biomass will have the highest possibility to meet the full potential.

During this project one of the demonstrated technologies have been spread in Sweden, which shows that the payback time is reasonable, even if both the electricity price and price of biomass is higher in Sweden than in EU countries. The price of these two parameters highly affects the payback time of the technology. Considered this and considered that several countries are introducing a higher price on CO₂ emissions, the potential for small scale CHP units will increase during coming years. The development has begun, and it will continue as more incentives are coming for using renewable resources.

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