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COST ASSESSMENT OF SELECTED DECENTRALISED CHP APPLICATIONS BASED ON BIOMASS COMBUSTION AND BIOMASS GASIFICATION

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ABSTRACT: Within this work, five case studies of CHP plants based on biomass combustion and four case studies based on biomass gasification have been investigated. Their annual and specific heat and electricity generation costs have been calculated. Moreover, through sensitivity analyses the influence of the investment costs, the fuel price and the annual full load operating hours on the specific electricity generation costs has been evaluated. In addition, the specific electricity generation costs have been compared with the relevant feed-in tariffs under Austrian framework conditions. From these investigations it could be concluded, that the support mechanism currently valid in Austria for green electricity generation from biomass is for CHP plants based on biomass combustion only sufficient in particular cases, where special framework conditions allow an economic operation. For CHP plants based on biomass gasification as well as for biomass CHP plants with a nominal electric capacity below 1 MW this support mechanism is definitely not suitable, as the electricity generation costs clearly exceed the respective feed-in tariffs. Therefore, higher feed-in tariffs for green electricity (especially for smaller electric capacities), secured for a long period of time (at least 15 years) are strongly recommended.
Keywords: combined heat and power generation (CHP), economic aspects, bio-energy policy

1 INTRODUCTION AND OBJECTIVES

According to the White Paper for a Community Strategy and Action Plan (1997) from the European Commission, the energy generation from biomass should be tripled and the electricity generation from biomass should even be increased by a factor of 10 by the year 2010 (based on the year 1995), which means, that the electricity generation from biomass should be increased from 81 PJ_{el} (1995) to 828 PJ_{el} in 2010.

A major contribution to achieve these goals could be decentralised combined heat and power (CHP) applications based on biomass combustion and biomass gasification (installation of new plants as well as retrofitting of existing heating systems). For decentralised CHP applications based on biomass combustion and biomass gasification plants with nominal electric capacities up to 20 MW_{el} are usually applied due to meaningful limitations concerning fuel supply distances and regional fuel availabilities.

The main objectives of this work were to make a cost assessment for the most relevant biomass CHP technologies based on biomass combustion and technologically promising demonstration projects based on biomass gasification and to investigate the framework conditions under which an economic operation is possible.

The study is based on previous publications of the authors [1; 2; 3; 4; 20; 21], which have been enhanced and updated in 2008.

2 METHODOLOGY

2.1 Rationale for the selection of the technologies compared

According to the current state-of-the-art, Stirling engine processes (< 100 kW_{el}), ORC processes (200 to 2,000 kW_{el}) and steam turbine processes (> 2,000 kW_{el}) are well suited technologies for decentralised CHP plants based on biomass combustion. Both ORC processes and steam turbine processes have already achieved market introduction and are well proven biomass CHP technologies. Stirling engines have recently reached the demonstration stage. These combustion based technologies have therefore been selected for detailed cost assessments.

For CHP plants based on biomass gasification with subsequent gas utilisation in gas engines co-current gasifiers (100 – 700 kW_{el}), counter-current gasifiers (100 – 2,000 kW_{el}) and fluidised bed gasifiers (> 2,000 kW_{el}) are available. CHP technologies based on biomass gasification are not yet technically fully developed. However, several prototypes and demonstration plants exist and are partly in operation. In comprehensive investigations [4] four CHP technologies based on biomass gasification have been identified, which have reached the demonstration stage and seem technologically promising concerning a future market introduction. These technologies have therefore been selected for detailed cost assessments.

2.2 Economic calculations according to the guideline VDI 2067

The guideline VDI 2067 [5] provided the basis for the heat and electricity generation cost calculations of the different processes compared. According to this guideline, the different types of costs are divided into the 4 cost groups costs based on capital, consumption costs, operating costs and other costs.

The costs based on capital consist of the annual capital and maintenance costs. All costs in connection with the energy generation itself, e.g. the fuel costs and the electricity (auxiliary energy) costs, are included in the group of consumption costs. The operating costs comprise costs originating from the operation of the plant, e.g. personnel costs. The other costs include costs such as insurance rates, overall dues, taxes and administration costs and are calculated as a percentage of the overall investment costs.

2.3 Methodology for the calculation of the electricity and heat generation costs

For combined heat and power generation (CHP) the heat and the power generation should be considered separately. The capital costs for electricity generation should therefore be based on additional investment costs, and consider only the surplus investment costs of a CHP plant in comparison to a conventional biomass combustion plant with a hot water boiler and the same thermal output. This approach seems to be meaningful because decentralised biomass CHP plants primarily produce process or district heat. Electricity generation is an alternative and implementation depends mainly on the profitability of the additional investment necessary. Moreover, it is possible by this approach to separate costs for electricity generation from costs for heat generation. This approach makes clear comparisons of costs for heat only and CHP applications possible and forms the basis for a correct calculation of the electricity generation costs.

The method to be followed was therefore to take the additional annual costs of the electricity generation in comparison to a heat-only plant with the same thermal power output into consideration and to calculate heat generation costs and electricity generation costs separately. For the calculation of the heat generation costs the heat distribution system has not been taken into account. Therefore, the heat generation costs shown in the following sections are heat generation costs ex CHP plant.

2.4 Abbreviations

BFB .... bubbling fluidised bed
CFB .... circulating fluidised bed
CHP .... combined heat and power generation
d.b. .... dry basis
DD .... downdraft gasifier
el..................... electric
ESP .... electrostatic precipitator
FB .... fluidised bed gasifier
GasE .... gas engine
I .... investment costs
NCV .... net calorific value
ORC .... Organic Rankine Cycle process
RME .... rapeseed methyl ester
ST .... steam turbine process
STE .... Stirling engine process
th .... thermal
TOC .... total organic carbon
UD .... updraft gasifier
wt.% .... weight percent

3 SHORT TECHNOLOGICAL DESCRIPTIONS OF THE TECHNOLOGIES INVESTIGATED

3.1 CHP technologies based on biomass combustion

The Stirling engine applied in the STE 35 plant is a hermetic four cylinder engine with a nominal electric power output of 35 kW_{el} and has been developed in a cooperation between the Technical University of Denmark, MAWERA Holzfeuerungsanlagen GesmbH, an Austrian biomass furnace and boiler manufacturer, and BIOS BIOENERGIESYSTEME GmbH, an Austrian development and engineering company. In a second step a small-scale CHP plant based on a 75 kW_{el} hermetic eight cylinder Stirling engine for biomass fuels was developed from the same consortium. Both engines have been installed and tested in 4 pilot plants in Austria, achieved in total already 19,000 operating hours and have recently reached the demonstration stage. Detailed technological descriptions and respective operating experiences can be found in literature [6; 7; 8; 9].

Both ORC and steam turbine processes are well developed and proven biomass CHP technologies. Detailed technological descriptions can be found in literature (e.g. [9; 10; 11]).

3.2 CHP technologies based on biomass gasification

3.2.1 Downdraft gasifier with gas engine (Biomass Engineering Ltd. technology, UK) – nominal electric capacity 540 kW_{el} (DD-GasE 540)

DD-GasE 540 is based on a single-stage, atmospheric air-blown downdraft fixed bed gasifier with round cross-section and typical contradiction in the oxidation zone. To minimise heat losses the gasifier is equipped with an insulation in the inner part of the reactor and a double jacket designed as a heat exchanger between incoming gasification air and producer gas outflow. Fuel is fed into the upper part of the gasifier by a hydraulic sluice system in batch mode. Drying and pyrolysis takes place in the upper part of the reactor. Gasification air is pre-heated in the double jacket and then fed into the oxidation zone via nozzles, which are positioned around the oxidation zone. The producer gas is formed in the reduction zone from the products from the oxidation zone. The producer gas leaves the reduction zone above the grate through the double jacket, where heat from the producer gas is transferred to incoming gasification air. A part of the ash and charcoal particles is also removed from the gasifier with the producer gas. The remaining charcoal in the gasifier with a carbon content of almost 90% falls through the grate and is fed in an air-tight container by a conveying screw.

The first gas cleaning step is a ceramic hot gas filter, where the producer gas is almost completely de-dusted. The filter cake is fed into the same air-tight container, where the charcoal is collected. In a next step the producer gas is cooled down from about 400°C to 35°C. Water and small amounts of remaining tars are condensed. Both sensible and latent heat are released to the environment. A droplet separator is placed after the gas cooler to remove remaining water droplets from the producer gas. The producer gas is then fed into a buffer store from where the gas engine is supplied with gas. The buffer store compensates fluctuations concerning volume flow and heating value.

Residues from the process are the carbon-rich ashes from the gasifier as well as the condensate from the gas cooler and the droplet separator, which is cleaned by a two-stage activated carbon filter.

Useful heat is provided from the gas engine cooling circuit and from flue gas cooling as hot water (feed temperature about 95°C)

Electricity generation takes place in a gas engine with an electric capacity of 540 kW_{el}.

The fuel quality required is comparatively high. A particle length of the wood chips of 25 to 100 mm without fines and a moisture content between 15 and 20 wt.% (w.b.) is necessary.

The technology is currently introduced into the market. The cumulative operating hours achieved from the gas engines in all pilot and demonstration plants amount to more than 35,000 h. Single units achieved up to 9,000 engine operating hours (status 10/2007).

More detailed information regarding this technology can be found in literature [12].

3.2.2 Downdraft gasifier with gas engine (Pyroforce® technology, CH) – nominal electric capacity 600 kW_{el} (DD-GasE 600)

DD-GasE 600 is based on an atmospheric air-blown downdraft (and partly cross-flow) fixed bed gasifier with round cross-section. Fuel is fed via a cellular wheel sluice into the upper part of the gasifier. Drying and pyrolysis of the fuel takes place in the upper part of the gasifier. In the following oxidation zone the products from pyrolysis are partly oxidised. The air needed for oxidation is sucked through nozzles positioned around the reactor in the middle section as well as trough a lance in the middle of the reactor. At the bottom of the gasifier the products from oxidation are reduced at the charcoal. The producer gas is removed in cross-flow via an annular gap around the reaction zone. Together with the producer gas large amounts of incomplete gasified charcoal and mineral compounds are removed. The conversion of the remaining charcoal in the reaction zone at the bottom of the gasifier is almost complete. The resulting ash (TOC < 5 wt.% d.b.) is fed into an ash container.

In a first gas cleaning step major parts of charcoal and ash particles are removed in a cyclone. The removed solid residues have a high carbon content of up to 70%. Afterwards, the producer gas is cooled in a gas-air heat exchanger, which is followed by a pre-coated baghouse filter. The baghouse filter is followed by a scrubber using RME, where the producer gas is further cooled and cleaned, before it is fed into the gas engine.

Residues from this process are the carbon-rich ashes from the cyclone.

Useful heat is provided from the gas engine cooling circuit and the flue gas cooling as hot water.

Electricity generation takes place by a gas engine with an electric capacity of 600 kW_{el}.

Fuel should be wood chips G50 according to ÖNORM M 7133. The amount of fines should be below 5 wt.%.

The technology has been demonstrated successfully, market introduction is currently starting. The gasifier achieved already more than 24,000 operating hours and the gas engine almost 15,000 operating hours (status 9/2007).

More detailed information regarding this technology can be found in literature [13; 14].

3.2.3 Updraft gasifier with gas engine (Babcock & Wilcox Vølund technology, DK) and ORC process – nominal electric capacity 2,076 kW_{el} (UD-GasE+ORC 2,076)

UD-GasE+ORC 2,076 is based on an atmospheric air-blown updraft fixed bed gasifier with a single-stage reactor. Fuel is fed into the top of the gasifier. The gasification medium (pre-heated and humidified air) is fed via a conical rotating grate into the bottom of the reactor and flows upwards. The fuel is dried and heated up in the upper section of the reactor. Below the heating and drying zone the fuel reaches the pyrolysis zone. Pyrolysis gases formed in this zone flow upwards and leave the reactor at the top without passing high temperature regions, which leads to a high tar content in the producer gas. The charcoal from the pyrolysis zone enters the lower section of the reactor with high temperatures (up to 1,100°C). The charcoal is partly reduced to H_2 and CO (with H_2O and CO_2 from the oxidation zone). The remaining carbon is combusted in the oxidation zone at the grate and provides the necessary heat for the process. The carbon conversion is almost complete due to the combustion of the charcoal in the oxidation zone with excess air (carbon content below 0.7 wt.% (d.b.) in the ash, which is collected in an ash container).

The producer gas leaves the reactor with about 75°C, a high tar and a low particle content and is saturated with water. In a two-stage gas cooler the producer gas is cooled to 40°C, major parts of contained water and tars are condensed. The two heat exchangers are followed by a wet electrostatic precipitator (ESP), where remaining tar and water droplets as well as particles are removed. The cleaned producer gas is then fed into the gas engine via a fan.

The condensates from the producer gas coolers and the ESP are collected and in a first step cleaned by a filter, where the contained solids are almost completely removed (small amounts, to be disposed of). The filtered condensate is fed into a conventional oil separator, where heavy tars (net calorific value about 29 kJ/kg) are separated and stored in a heated tank. The remaining condensate is treated thermally in order to separate organic compounds from the water. The volatile organic fractions are recycled to the gasifier, the cleaned waste water can be discharged into a sewer. The heavy tars separated can e.g. be used in an adapted oil boiler to provide the peak load for a district heating system or in a thermal oil boiler to operate a small ORC unit producing additional electricity. The latter option is investigated in this paper.

Residues from the process are the cleaned waste water, which has to be discharged, and well burned ashes.

Useful heat as hot water is provided from the gas engine cooling circuit, the flue gas cooling and the ORC condenser.

Electricity generation is done in a gas engine with an electric capacity of 1,930 kW_{el} as well as in an ORC unit with an electric capacity of 146 kW_{el}. The ORC process is operated by utilising the heavy tars from the waste water treatment system. The overall electric capacity of the process amounts to 2,076 kW_{el}.

The requirements regarding fuel quality are moderate compared to the previously described processes. The gasifier can use wood chips with a moisture content between 35 and 55 wt.% (w.b.). There are no special requirements related to the particle size.

The technology has been demonstrated successfully and market introduction is currently starting. The gasifier achieved already about 100,000 operating hours, the gas engine about 40,000 operating hours (status 6/2007).

More detailed information regarding this technology can be found in literature [15; 16].

3.2.4 Allothermal fluidised bed gasifier with gas engine (Repotec / TU Vienna technology, Güssing, A) and ORC process – nominal electric capacity 4,500 kW_{el} (FB-GasE+ORC 4,500)

FB-GasE+ORC 4,500 is based on an allothermal steam-blown dual-bed fluidised bed gasifier. The reactor consists of a BFB gasification and an CFB combustion unit. The fuel is fed by a conveying screw into the gasification zone, where added steam and mixing with hot bed material provide the energy for gasification. The producer gas shows a comparatively low tar content. Remaining charcoal together with bed material is transported into the combustion zone, where the charcoal is burned and the bed material is heated up under addition of a part of the producer gas (depending on the moisture content of the fuel). Particles from the baghouse filter and tars from the scrubber are combusted in the combustion zone as well. The heated bed material is separated from the flue gas and recirculated into the gasification zone.

The producer gas from the gasification zone and the flue gas from the combustion zone are extracted, cooled and cleaned separately.

The producer gas is cooled in a first step to about 150°C in a heat exchanger, where heat is transferred to a pressurised hot water circuit (which produces the steam needed for gasification and provides heat for a district heating system). The cooled producer gas is fed into a pre-coated baghouse filter, where particles and tars are separated. The solid residues are fed into the combustion zone, where remaining carbon is combusted. In a following RME-scrubber the producer gas is further cooled, water is condensed and tars are removed. The condensate is fed into a sedimentation bond, where remaining oil is separated from the water phase. As the water phase is used for steam production and the residues from the producer gas filter as well as the used washing medium are fed into the combustion zone, no residues result from the gas cleaning. The cleaned producer gas is finally transported by a fan to the gas engines.

Alternatively, the heat from the high temperature sources can be transferred to a thermal oil circuit (instead of a hot water circuit). In this case, the thermal oil can drive an ORC module in order to increase the electric efficiency. This option is further investigated in this paper.

The flue gas from the combustion zone is cleaned by a cyclone, before it enters a afterburning chamber. Then the flue gas is cooled stepwise in three heat exchangers to about 150°C. Finally, a baghouse filter separates fly ash particles before the flue gas is transported by a fan into the chimney.

Residues from this process are well burned ashes from the combustion unit.

Useful heat is provided from the gas engine cooling circuit, the flue gas cooling (both gas engine and flue gas from the combustion chamber) and the ORC condenser.

Electricity generation takes place in a gas engine and in an ORC process. The electric capacity of the gas engine amounts to 3,700 kW_{el} and of the ORC process to 800 kW_{el}. Totally, the electric capacity of the process amounts to 4,500 kW_{el}.

The fuel used in the gasifier should be wood chips with a moisture content between 15 and 50 wt.% (w.b.). There are no special requirements relevant concerning the particle size.

The technology has been demonstrated very successfully. Market infroduction is currently starting. The gasifier achieved already 32,700 and the gas engine already 28,400 operating hours (status 9/2007).

More detailed information regarding this technology can be found in literature [17; 18].

4 RESULTS

4.1 Comparison of the technologies

4.1.1 Technical data

The technical data of the biomass CHP plants investigated are summarised in Table I. The electric capacities of the CHP plants based on biomass combustion range from 35 kW_{el} to 5,000 kW_{el}. The CHP plants based on biomass gasification are also within this range and show electric capacities between 540 kW_{el} and 4,500 kW_{el}. Thus, the plants investigated cover the most relevant capacity range for decentralised biomass CHP applications. The thermal capacities of the CHP units based on biomass combustion range from 250 kW_{th} to 19 MW_{th}, the thermal capacities of the plants based on biomass gasification vary between 600 kW_{th} and 5 MW_{th}.

Table I: Technical data of the biomass CHP plants investigated

		Combustion based biomass CHP applications					Gasification based biomass CHP applications			
Parameter	**Unit**	**STE 35**	**STE 70**	**ORC 650**	**ORC 1,570**	**ST 5,000**	**DD-GasE 540**	**DD-GasE 600**	**UD-GasE+ ORC 2,076**	**FB-GasE+ ORC 4,500**
Fuel power input CHP (nominal conditions)	[kW_{NCV}]	320	635	4,333	10,720	29,042	2,064	2,182	7,044	13,405
Electric capacity CHP (nominal conditions)	[kW_{el}]	35	70	650	1,570	5,000	540	600	2,076	4,500
Useful heat capacity CHP (nominal conditions)	[kW_{th}]	250	500	3,250	7,650	19,061	598	790	3,738	4,975
Full load operating hours CHP	[h/a]	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Annual electric efficiency	[%]	10.5	10.5	14.0	14.0	18.0	26.2	27.5	29.5	33.6
Annual total efficiency	[%]	86.0	86.0	86.0	86.0	82.8	55.1	63.7	82.5	70.7
Electrical flow index	[-]	0.14	0.14	0.19	0.19	0.28	0.90	0.76	0.56	0.90
Specific electricity consumption CHP (total)	[kWh_{el}/MWh_{th}]	20.0	20.0	35.0	35.0	30.0	42.9	33.4	21.1	51.7
Specific electricity consumption (heat related)	[kWh_{el}/MWh_{th}]	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
Total electricity consumption CHP	[kWh_{el}/a]	34,400	68,800	838,500	2,025,300	4,140,000	292,921	278,556	736,052	2,939,145
Electricity consumption heat related	[kWh_{el}/a]	19,630	39,260	260,743	629,794	1,404,000	46,644	61,620	291,595	388,050
Electricity consumption CHP related	[kWh_{el}/a]	14,770	29,540	577,757	1,395,506	2,736,000	246,277	216,936	444,457	2,551,095
Gross electricity generation	[kWh_{el}/a]	210,000	420,000	3,900,000	9,420,000	30,000,000	3,240,000	3,600,000	12,453,600	27,000,000
Net electricity generation	[kWh_{el}/a]	195,230	390,460	3,322,243	8,024,494	27,264,000	2,993,723	3,383,064	12,009,143	24,448,905
Heat generation CHP	[kWh_{th}/a]	1,510,000	3,020,000	20,057,143	48,445,714	108,000,000	3,588,000	4,740,000	22,430,400	29,850,000
Total fuel energy input CHP	[kWh_{NCV}/a]	2,000,000	4,000,000	27,857,143	67,285,714	166,666,667	12,385,321	13,090,909	42,262,774	80,430,000
Fuel energy input heat related	[kWh_{NCV}/a]	1,715,909	3,431,818	22,792,208	55,051,948	122,727,273	4,077,273	5,386,364	25,489,091	33,920,455
Fuel energy input CHP related	[kWh_{NCV}/a]	284,091	568,182	5,064,935	12,233,766	43,939,394	8,308,048	7,704,545	16,773,683	46,509,545

The main differences in the technical data between combustion and gasification based biomass CHP applications result from their different annual electric and total efficiencies. The annual electric efficiencies of biomass CHP applications based on gasification are clearly higher compared to combustion based systems. The annual total efficiency of gasification based systems is usually lower due to the comparatively low thermal efficiency.

All plants investigated operate in heat controlled mode which should be a basic requirement for decentralised CHP plants based on biomass combustion or biomass gasification.

All systems investigated are biomass CHP systems integrated in large district heating or process heat systems. The biomass CHP unit covers the base load in all system. Mean and peak thermal load in district heating systems are usually covered by a second biomass hot water boiler or a combination of a biomass hot water boiler and an oil-fired peak load boiler. However, these base and peak load boilers have not been considered for this evaluation. This approach justifies the high annual full load operating hours of the CHP plants of 6,000 h/a (if relevant process heat consumers are available their number can increase to more than 7,000 h/a). Between 1.5 and 108.0 GWh/a of heat are produced by the CHP plants investigated. The annual net electricity generation of the biomass CHP plants investigated varies between 195 MWh_{el}/a and 27 GWh_{el}/a. The specific electricity consumption of the CHP plants based on biomass combustion varies between 20 and 35 kWh_{el}/MWh_{th} leading to an electricity consumption (auxiliary energy) between 13.8% and 21.5% of the gross electricity generation. The specific electricity generation of the CHP plants based on biomass gasification varies between 21 and 52 kWh_{el}/MWh_{th}. Due to the different relation between heat and electricity produced from the systems based on biomass combustion and biomass gasification this results in an auxiliary energy demand between 5.9% and 10.9% of the gross electricity generation, which is clearly lower compared to the technologies based on biomass combustion.

4.1.2 General economic data

Utilisation periods and maintenance costs of the process units have been chosen according to usual depreciation periods and maintenance efforts for energy generation units.

Due to the comparatively high complexity of biomass CHP technologies the utilisation periods of all electricity related units have been chosen with 10 years.

An overview of the utilisation periods and the maintenance costs for the different units of biomass CHP plants is shown in Table II.

Table II: Utilisation periods and maintenance costs for the different units of biomass CHP plants

Unit	Heat related		CHP related		
	Utilisation period [a]	Maintenance costs [(% of I)/a]	Utilisation period [a]	Maintenance costs (comb.) [(% of I)/a]	Maintenance costs (gasif.) [(% of I)/a]
Building, outside facilities, infrastructure	25	1.0	10	1.0	1.0
Fuel storage unit	25	1.0	10	1.0	1.0
Furnace and boiler / gasifier	15	2.0	10	2.0	3.0
Flue gas cleaning	15	2.0	10	2.0	2.0
Ash container and conveyor	15	2.0	10	2.0	2.0
Heat recovery	15	2.0	10	2.0	2.0
Fuel conveyor	15	2.0	10	2.0	2.0
Crane	15	1.0	10	1.0	1.0
Electric installations	15	2.0	10	2.0	2.0
Hydraulic installations	15	2.0	10	2.0	2.0
Steelworks	15	1.0	10	1.0	1.0
CHP module(s)	-	-	10	2.0	8.0 - 10.1
Vehicles	15	3.0	10	3.0	3.0
Planning	15	0.0	10	0.0	0.0

The interest rate has been chosen with 7% for all plants investigated, based on realistic Austrian framework conditions.

All prices used for the economic calculations are related to summer 2007.

Due to the fact that the Austrian feed-in tariffs are fixed, these feed-in tariffs have to cover also future price increases relevant for the operation of the plants. Therefore, for the calculation of the electricity generation costs a general price increase of 2.5% p.a. has been considered.

For the calculation of the heat generation costs this indexation is not necessary, as with increasing operation, consumption and other costs also the heat price, and consequently the revenues, increase.

4.1.3 CHP and heat related investment costs

The CHP related investment costs of the plants investigated are shown in Table III, the heat related investment costs in Table IV.

The highest total investment costs with more than 23 million € are shown by the gasification based FB-GasE+ORC 4,500 system with 4.5 MW_{el}. The biomass combustion based CHP plant based on a Stirling engine with 35 kW_{el} shows the lowest investment costs with about 0.5 million € (STE 35). As the plants compared have different electric and thermal capacities, these figures are, however, not directly comparable. More important are the specific investment costs (both CHP and heat related), which are discussed later in this section.

Austrian legal framework conditions do not allow investment subsidies for the electricity related parts of biomass CHP plants (due to the subsidy of the electricity generation by the increased feed-in tariffs). The usual investment subsidy granted for the heat related part of the plant (except land, vehicles and other costs) amounts to 30% of the total heat related investment costs, if the plant is operated in heat controlled mode.

Table III: CHP related investment costs of the biomass CHP plants investigated

Plant unit	Unit	Combustion based biomass CHP applications: STE 35	STE 70	ORC 650	ORC 1,570	ST 5,000	Gasification based biomass CHP applications: DD-GasE 540	DD-GasE 600	UD-GasE+ ORC 2,076	FB-GasE+ ORC 4,500
Building, outside facilities, infrastructure	[€]	10,000	15,000	210,000	320,000	600,000	218,000	224,000	340,000	468,000
Furnace and boiler / gasifier	[€]	68,000	106,000	600,000	1,170,000	4,500,000	1,533,000	2,004,000	4,975,000	12,470,000
Flue gas / producer gas cleaning	[€]	included	included	15,000	40,000	300,000	included	included	included	included
Ash container and conveyor	[€]	included	included	10,000	20,000	50,000	included	included	included	included
Heat recovery	[€]	included	included	30,000	30,000	280,000	included	included	included	included
Fuel conveyor	[€]	included	included	10,000	30,000	130,000	included	included	included	included
Crane	[€]	included	included	5,000	5,000	10,000	included	included	included	included
Electric installations	[€]	7,000	10,000	70,000	200,000	950,000	included	included	included	included
Hydraulic installations	[€]	9,000	14,000	50,000	125,000	1,300,000	included	included	included	included
Steelworks	[€]	included	included	30,000	40,000	200,000	included	included	included	included
CHP module(s)	[€]	70,000	140,000	1,050,000	1,675,000	2,500,000	660,000	720,000	2,315,000	4,575,000
Planning	[€]	20,000	35,000	213,000	367,000	931,000	215,000	276,000	630,000	1,455,000
Fuel storage unit	[€]	included	included	50,000	100,000	200,000	10,000	163,000	242,000	677,000
Vehicles	[€]	included	included	included	included	included	25,000	25,000	50,000	140,000
Investment costs CHP related	**[€]**	**184,000**	**320,000**	**2,343,000**	**4,122,000**	**11,951,000**	**2,661,000**	**3,412,000**	**8,552,000**	**19,785,000**
Specific investment costs CHP related	**[€/kW$_{el}$]**	**5,257**	**4,571**	**3,605**	**2,625**	**2,390**	**4,928**	**5,687**	**4,120**	**4,397**

Table IV: Heat related investment costs of the biomass CHP plants investigated

Plant unit	Unit	Combustion based biomass CHP applications: STE 35	STE 70	ORC 650	ORC 1,570	ST 5,000	Gasification based biomass CHP applications: DD-GasE 540	DD-GasE 600	UD-GasE+ ORC 2,076	FB-GasE+ ORC 4,500
Building, outside facilities, infrastructure	[€]	90,000	135,000	900,000	1,380,000	2,000,000	153,000	187,000	907,000	1,088,000
Furnace and boiler	[€]	129,000	194,000	600,000	700,000	2,100,000	307,000	377,000	1,448,000	1,580,000
Flue gas cleaning	[€]	included	included	185,000	260,000	500,000	included	included	included	included
Ash container and conveyor	[€]	included	included	50,000	110,000	200,000	included	included	included	included
Heat recovery	[€]	included	included	50,000	80,000	200,000	included	included	included	included
Fuel conveyor	[€]	included	included	70,000	130,000	470,000	included	included	included	included
Crane	[€]	included	included	20,000	25,000	40,000	included	included	included	included
Electric installations	[€]	21,000	32,000	130,000	200,000	550,000	included	included	included	included
Hydraulic installations	[€]	31,000	46,000	250,000	300,000	800,000	included	included	included	included
Steelworks	[€]	included	included	40,000	60,000	200,000	included	included	included	included
Planning	[€]	33,000	50,000	260,000	345,000	629,000	40,000	49,000	215,000	247,000
Fuel storage unit	[€]	included	included	300,000	600,000	800,000	included	included	333,000	418,000
Vehicles	[€]	included	included	included	included	included	15,000	15,000	70,000	100,000
Investment costs heat related	**[€]**	**304,000**	**457,000**	**2,855,000**	**4,190,000**	**8,489,000**	**515,000**	**628,000**	**2,973,000**	**3,433,000**
Specific investment costs heat related	**[€/kW$_{th}$]**	**1,216**	**914**	**878**	**548**	**445**	**861**	**795**	**795**	**690**

All economic calculations have been performed without consideration of any investment funding. The influence of investment funding and/or of investment cost variations will be discussed on the basis of sensitivity analyses in Section 4.2.1.

The specific CHP and heat related investment costs of the biomass CHP plants investigated are visualised in Figure 1.

The combustion based systems show a clear economy-of-scale-effect both concerning heat and CHP related investment costs. The highest specific investment costs within the combustion based systems occur for the Stirling engine process with 35 kW$_{el}$ (mainly due to the small electric capacity of the Stirling engine and its novelty). The biomass CHP plant based on a steam turbine process shows the lowest specific investment costs, mainly due to the higher electric capacity and the fact, that the steam turbine process is a well proven technology. The specific investment costs of the ORC process are located between the Stirling engine and the steam turbine process, which is also due to the medium position concerning the electric capacity.

The gasification based systems do not show this economy-of-scale-effect concerning the specific CHP related investment costs. The highest specific CHP related investment costs are shown by the DD-GasE 600 system with an electric capacity of 600 kW$_{el}$, the lowest by the UD-GasE+ORC 2,076 system with about 2.1 MW$_{el}$. The specific CHP related investment costs of the systems with the lowest (DD-GasE 540) and highest (FB-GasE+ORC 4,500) electric capacity are situated between these two systems. The specific CHP related investment costs of all systems based on biomass gasification remain clearly above the ORC process systems based on biomass combustion. The reason for this is the early stage of development of the gasification systems as well as their higher level of complexity. This indicates a certain cost reduction potential of the gasification based systems by further technological development.

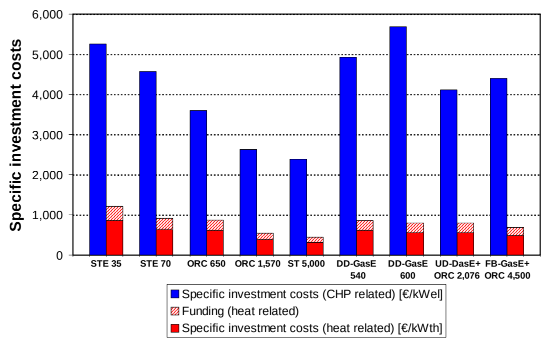

Figure 1: Specific CHP and heat related investment costs of the biomass CHP plants investigated

The heat related investment costs of all plants investigated include only conventional biomass combustion plants with hot water boilers and the same thermal output as the respective CHP plant (see also Section 2.3). Although all calculations have been done without consideration of investment funding, in Figure 1 it is indicated, which influence a 30% investment funding of the heat related part of the plant would have on the specific heat related investment costs (as granted under present Austrian framework conditions). A more detailed discussion of investment subsidies will be done in Section 4.2.1.

4.1.4 Electricity and heat generation costs

The calculation of the annual and specific electricity generation costs is shown in Table V.

For all biomass CHP plants investigated a utilisation of 100% forest wood chips as fuel has been assumed, as forest wood chips are a common and available fuel in Austria. The typical price for wood chips delivered to the plant usually ranges between 20 and 24 €/MWh$_{NCV}$, depending on regional framework conditions. For the economic evaluations of all plants investigated an average fuel price of 22 €/MWh$_{NCV}$ has been considered.

Table V: Specific and annual electricity generation costs of the biomass CHP plants investigated
Explanations: data given for the 6,000 hours per year of operation; cost increase of 2.5% p.a. considered

		Combustion based biomass CHP applications					Gasification based biomass CHP applications			
Parameter	**Unit**	**STE 35**	**STE 70**	**ORC 650**	**ORC 1,570**	**ST 5,000**	**DD-GasE 540**	**DD-GasE 600**	**UD-GasE+ ORC 2,076**	**FB-GasE+ ORC 4,500**
Interest rate	[%/a]	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Capital costs	[€/a]	26,197	45,561	326,472	572,642	1,673,078	377,443	462,585	1,183,157	2,720,549
Maintenance costs	[€/a]	3,180	5,550	39,150	69,450	208,300	111,301	135,793	354,779	750,023
Costs based on capital	**[€/a]**	**29,377**	**51,111**	**365,622**	**642,092**	**1,881,378**	**488,744**	**598,378**	**1,537,936**	**3,470,572**
Specific costs based on capital	**[€/kWh$_{el}$]**	**0.1399**	**0.1217**	**0.0937**	**0.0682**	**0.0627**	**0.1508**	**0.1662**	**0.1235**	**0.1285**
Fuel price	[€/kWh$_{NCV}$]	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Ash disposal costs	[€/a]	71	143	1,271	3,070	11,027	2,085	1,934	4,209	11,672
Fuel costs	[€/a]	7,071	14,143	126,071	304,510	1,093,695	206,795	191,774	417,513	1,157,668
Electricity price (own needs)	[€/kWh$_{el}$]	0.156	0.156	0.156	0.156	0.149	0.156	0.156	0.149	0.149
Electricity costs	[€/a]	2,310	4,620	90,361	218,257	408,758	38,518	33,929	66,402	381,134
Operating agents gas production and gas cleaning	[€/a]	0	0	0	0	0	0	13,379	0	294,630
Operating agents gas engine	[€/a]	0	0	0	0	0	5,515	5,077	19,938	26,152
Credit for utilisation of residual material	[€/a]	0	0	0	0	0	-25,732	-10,186	0	0
Consumption costs	**[€/a]**	**9,453**	**18,905**	**217,703**	**525,838**	**1,513,480**	**227,181**	**235,906**	**521,563**	**1,871,256**
Specific consumption costs	**[€/kWh$_{el}$]**	**0.0450**	**0.0450**	**0.0558**	**0.0558**	**0.0504**	**0.0701**	**0.0655**	**0.0419**	**0.0693**
Hourly rate - personnel costs	[€/h]	28.3	28.3	28.3	28.3	33.9	33.9	33.9	33.9	33.9
Annual working hours CHP	[h/a]	100	120	700	1,000	4,400	1,830	1,390	4,130	7,560
Total personnel costs CHP	[€/a]	2,829	3,394	19,800	28,285	149,346	62,114	47,180	140,181	256,603
Specific additional heat generation costs CHP	[€/MWh$_{th}$]	5.07	3.44	4.39	2.48	1.75	included	included	included	included
Additional heat generation costs CHP	[€/a]	1,268	1,721	19,566	26,713	67,719	included	included	included	included
Share of general operation costs CHP	[(% of I_{CHP})/a]	0.5	0.5	0.2	0.2	0.8	included	included	included	included
General operation costs CHP	[€/a]	920	1,600	4,686	8,244	95,608	included	included	included	included
Land rent	[€/a]	417	530	3,095	5,779	11,968	3,807	2,965	5,047	26,221
Operation costs	**[€/a]**	**5,433**	**7,245**	**47,146**	**69,021**	**324,640**	**65,921**	**50,145**	**145,228**	**282,824**
Specific operation costs	**[€/kWh$_{el}$]**	**0.0259**	**0.0173**	**0.0121**	**0.0073**	**0.0108**	**0.0203**	**0.0139**	**0.0117**	**0.0105**
Share of other costs	[(% of I_{CHP})/a]	1.0	1.0	1.0	1.0	1.0	1.2	1.2	1.2	1.2
Other costs	**[€/a]**	**1,840**	**3,200**	**23,430**	**41,220**	**119,510**	**31,932**	**40,944**	**102,624**	**237,420**
Specific other costs	**[€/kWh$_{el}$]**	**0.0088**	**0.0076**	**0.0060**	**0.0044**	**0.0040**	**0.0099**	**0.0114**	**0.0082**	**0.0088**
Total electricity generation costs	**[€/a]**	**46,104**	**80,461**	**653,901**	**1,278,171**	**3,839,008**	**813,778**	**925,372**	**2,307,351**	**5,862,072**
Specific electricity generation costs	**[€/kWh$_{el}$]**	**0.2195**	**0.1916**	**0.1677**	**0.1357**	**0.1280**	**0.2512**	**0.2570**	**0.1853**	**0.2171**

Typical ash disposal costs under Austrian framework conditions are about 100 €/t. The ash content has been assumed to be 1.0 wt.% (d.b.), which is a typical value for soft wood with bark [19], which formed the basis for the calculation of the annual ash disposal costs.

The electricity price (own needs for auxiliary energy) decreases with increasing consumption. For small consumers a price of 0.12 €/kWh$_{el}$ is realistic under Austrian framework conditions. For larger consumers an electricity price of 0.10 €/kWh$_{el}$ has been taken into account.

The gasification based processes DD-GasE 600 and FB-GasE+ORC 4,500 require additional operating agents for gas production and gas cleaning. All gasification based plants need in addition engine oil which has to be changed in regular periods. These operating agents have been considered on the basis of experiences from the demonstration plants.

Both the DD-GasE 540 and the DD-GasE 600 system produce residues, which are rich in carbon and can therefore be used as a fuel. For these residues credits for their utilisation have therefore been considered (15 €/MWh$_{NCV}$).

The hourly rate for the operating personnel for the combustion based CHP plants with Stirling engine and ORC process amounts to 25 €/h (based on typical Austrian salaries). The hourly rate for personnel operating steam processes and all gasification processes is higher (30 €/h), because specially skilled operating personnel is required. The annual working hours have been chosen according to practical experiences of plant operators and manufacturers for the different plants, separated into the heat and CHP related part.

The specific additional heat generation costs of the CHP plants based on biomass combustion comprise the costs for the heat generation needed for the electricity production, apart from the consumption and capital costs, which are considered separately. Thus they include the heat generation costs caused by the operating costs and the other costs and they have been calculated specifically for each plant investigated. For the CHP plants based on biomass gasification these costs are not expressed separately, as these costs are already included in the overall costs.

The general operation costs have been chosen based on practical experiences specifically for each technology for CHP plants based on biomass combustion. For the CHP plants based on biomass gasification these costs are considered in the cost sections “operating agents gas production, gas cleaning and gas engine”.

The required areas for the CHP plants have been estimated on the basis of information from the plant manufacturers as well as practical experiences. As an average land costs of 50 €/m^2 have been taken into account. The land rent has been calculated under consideration of the interest rate.

The heat related other costs have been chosen with 0.5% p.a. of the heat related investment costs (according to guideline VDI 2067 [5]). The CHP related other costs for the plants based on biomass combustion are assumed to be higher (1.0% p.a. of the CHP related investment costs) due to the higher insurance costs. For the plants based on biomass gasification the other costs have assumed to be 1.2% p.a. of the CHP related investment costs, as again higher insurance costs must be expected for these plants.

Figure 2 shows the specific electricity generation costs of the biomass CHP plants investigated in comparison to the respective feed-in tariffs.

The Austrian feed-in tariffs depend both on the electric capacity of the CHP plant and on the biomass fuel used. As all plants investigated are assumed to use 100% wood chips as fuel, only the electric capacities determine the feed-in tariffs. For the plants with electric capacities below 2 MW$_{el}$ a feed-in tariff of 15.64 €Cent/kWh$_{el}$ is valid. For the other plants a feed-in tariff of 14.94 €Cent/kWh$_{el}$ must be taken as a basis.

The specific electricity generation costs of the plants based on biomass combustion range between 0.1280 €/kWh$_{el}$ and 0.2195 €/kWh$_{el}$, whereas the Stirling engine process with 35 kW$_{el}$ shows the highest, and the steam turbine process shows the lowest (economy-of-scale-effect, see Figure 2). Such an economy-of-scale-effect can not be seen for the plants based on biomass gasification, as the plants with the lowest (DD-GasE 540) and highest (FB-GasE+ORC 4,500) electric capacity have specific electricity generation costs between the two other systems compared.

The main cost category are the specific costs based on capital, which is especially true for all gasification based systems and the Stirling engine processes. The specific consumption costs are are the second largest cost category and the specific operation and other costs are of minor relevance.

The feed-in tariffs valid for the plants investigated are below the respective electricity generation costs calculated, except for ORC 1,570 and ST 5,000. Especially the plants with lower electric capacities (the Stirling engine processes) and all gasification based processes show considerably higher electricity generation costs compared to the respective feed-in tariffs.

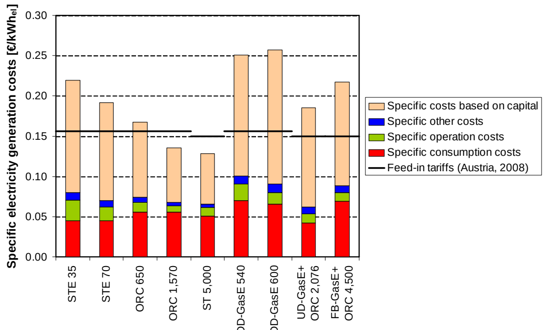

Figure 2: Specific electricity generation costs of the biomass CHP plants investigated

Table VI: Specific and annual heat generation costs of the biomass CHP plants investigated

Parameter	Unit	Combustion based biomass CHP applications: STE 35	STE 70	ORC 650	ORC 1,570	ST 5,000	Gasification based biomass CHP applications: DD-GasE 540	DD-GasE 600	UD-GasE+ ORC 2,076	FB-GasE+ ORC 4,500
Interest rate	[%/a]	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Capital costs	[€/a]	31,219	46,938	256,744	358,320	791,851	52,875	64,466	268,104	304,936
Maintenance costs	[€/a]	4,520	6,790	36,100	50,000	118,400	8,120	9,860	40,130	45,480
Costs based on capital	**[€/a]**	**35,739**	**53,728**	**292,844**	**408,320**	**910,251**	**60,995**	**74,326**	**308,234**	**350,416**
Specific costs based on capital	**[€/kWh$_{el}$]**	**0.0237**	**0.0178**	**0.0146**	**0.0084**	**0.0084**	**0.0170**	**0.0157**	**0.0137**	**0.0117**
Fuel price	[€/kWh$_{NCV}$]	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
Ash disposal costs	[€/a]	381	761	5,056	12,211	27,222	904	1,195	5,654	7,524
Fuel costs	[€/a]	37,750	75,500	501,429	1,211,143	2,700,000	89,700	118,500	560,760	746,250
Electricity price (own needs)	[€/kWh$_{el}$]	0.120	0.120	0.100	0.100	0.100	0.120	0.120	0.100	0.100
Electricity costs	[€/a]	2,356	4,711	26,074	62,979	140,400	5,597	7,394	29,160	38,805
Consumption costs	**[€/a]**	**40,486**	**80,972**	**532,558**	**1,286,333**	**2,867,622**	**96,202**	**127,089**	**595,573**	**792,579**
Specific consumption costs	**[€/kWh$_{th}$]**	**0.0268**	**0.0268**	**0.0266**	**0.0266**	**0.0266**	**0.0268**	**0.0268**	**0.0266**	**0.0266**
Hourly rate - personnel costs	[€/h]	25.0	25.0	25.0	25.0	30.0	30.0	30.0	30.0	30.0
Annual working hours	[h/a]	200	250	2,700	3,500	4,200	270	310	2,800	3,000
Personnel costs	[€/a]	5,000	6,250	67,500	87,500	126,000	8,100	9,300	84,000	90,000
Land rent	[€/a]	1,140	1,863	6,271	11,759	20,700	1,212	1,568	6,900	8,779
Operation costs	**[€/a]**	**6,140**	**8,113**	**73,771**	**99,259**	**146,700**	**9,312**	**10,868**	**90,900**	**98,779**
Specific operation costs	**[€/kWh$_{th}$]**	**0.0041**	**0.0027**	**0.0037**	**0.0020**	**0.0014**	**0.0026**	**0.0023**	**0.0041**	**0.0033**
Share of other costs	[(% of I_{th})/a]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Other costs	**[€/a]**	**1,520**	**2,285**	**14,275**	**20,950**	**42,445**	**2,575**	**3,140**	**14,865**	**17,165**
Specific other costs	**[€/kWh$_{th}$]**	**0.0010**	**0.0008**	**0.0007**	**0.0004**	**0.0004**	**0.0007**	**0.0007**	**0.0007**	**0.0006**
Total heat generation costs	**[€/a]**	**83,885**	**145,098**	**913,448**	**1,814,862**	**3,967,018**	**169,084**	**215,423**	**1,009,572**	**1,258,939**
Specific heat generation costs	**[€/kWh$_{th}$]**	**0.0556**	**0.0480**	**0.0455**	**0.0375**	**0.0367**	**0.0471**	**0.0454**	**0.0450**	**0.0422**
Specific heat generation costs (incl. 30% funding)	**[€/kWh$_{th}$]**	**0.0494**	**0.0434**	**0.0417**	**0.0352**	**0.0345**	**0.0428**	**0.0415**	**0.0415**	**0.0392**

This comparison shows, that the feed-in tariffs valid in Austria at present are usually not adequate to support and increase the number of biomass CHP plants based on biomass combustion below an electric capacity of about 1 MW$_{el}$. For CHP plants based on biomass gasification the feed-in tariffs currently valid in Austria are a completely insufficient support mechanism, as the specific electricity generation costs exceed by far the respective feed-in tariffs. Higher feed-in tariffs for green electricity (especially for smaller electric capacities), secured for a long period of time (at least 15 years) in combination with investment subsidies for highly innovative concepts are strongly recommended.

The calculation of the specific heat generation costs of the biomass CHP plants is shown in Table VI. They decrease with increasing plant capacities from 0.0556 €/kWh$_{th}$ for the Stirling engine process with 35 kW$_{el}$ to 0.0367 €/kWh$_{th}$ for the steam turbine process. Taking Austrian framework conditions into account, where 30% investment funding is granted for the heat related part of the plant (for heat controlled operation), the specific heat generation costs would be reduced to between 0.0494 €/kWh$_{th}$ and 0.0345 €/kWh$_{th}$, respectively. The heat generation costs calculated are heat generation costs ex plant without heat distribution costs (costs of the network of pipes).

4.2 Sensitivity analyses concerning electricity generation costs

The annual full load operating hours of the CHP plant and the fuel price are important influencing factors for the specific electricity generation costs. Therefore, in order to evaluate their impact, sensitivity analyses have been performed for these parameters, which are discussed in the following sections.

In addition, as the investment costs (especially for the Stirling engine processes and the gasification based processes) are expected to be able to be reduced by further technological development and serial production and as the steam turbine processes could become more expensive due to increasing raw material prices, also a variation of the investment costs has been considered within the sensitivity analyses. This variation of investment costs can also be considered similar to a variation of a possible investment subsidy (funding). Following, this sensitivity analysis also points out the influence of funding on the electricity generation costs.

These parameters also influence the specific heat generation costs. A detailed investigation has, however, not been done within this work.

4.2.1 Influence of the investment costs

The influence of the investment costs on the specific electricity generation costs is shown in Figure 3.

A reduction of investment costs is possible by investment funding or by a reduction of the manufacturing costs. An increase could happen due to increasing raw material prices. Under Austrian framework conditions investment funding for the electricity related part of biomass CHP plants is not possible. However, investment subsidies for the electricity related part may be available in other countries and can be evaluated by this sensitivity analysis.

Concerning manufacturing costs, a substantial cost reduction potential exists for Stirling engine processes. As soon as the first two or three small series have been produced the investment costs are expected to drop considerably. A certain reduction of manufacturing costs of ORC processes can be expected in particular by serial production (higher number of units of a certain size) and to a minor extent by further technological developments. However, this cost reduction potential is expected to be compensated by the increasing raw material prices so that no future net cost reduction potential for ORC processes is seen. Due to the high quantities of steam turbines already produced and their high state-of-the-art no cost reduction potential is seen for steam turbines. Due to the increasing raw material costs even an increase of investment costs must be expected.

The processes based on biomass gasification are in an early stage of development and a substantial investment cost reduction can be expected by further technological developments and finally by serial production.

A variation of the investment costs by ± 10% would lead to a variation of the specific electricity generation costs between ± 5.4% and ± 7.1%. There is no significant difference between combustion and gasification based plants.

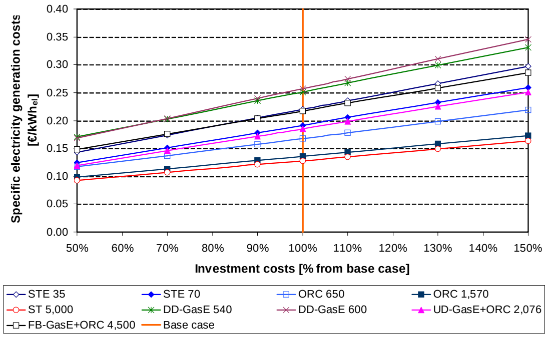

Figure 3: Influence of the change of the investment costs on the specific electricity generation costs

4.2.2 Influence of the fuel price

The influence of the fuel price on the specific electricity generation costs is shown in Figure 4.

A variation of the fuel price within the typical price range for wood chips between 20 to 24 €/MWh$_{NCV}$ leads to a variation of the specific electricity generation costs between ± 1.4% and ± 2.6%. A significant difference in the variations between combustion and gasification based processes can not be seen.

The use of other biomass fuels than forest wood chips would vary the fuel price in a much broader range. E.g. waste wood is usually available cost-free. In some cases, even a small price is paid if waste wood is used, depending on its quality. However, the use of other fuels than forest wood chips would – at least in Austria – decrease the feed-in tariffs considerably (by 40% in case of waste wood, by 25% in case of industrial wood chips). In case of waste wood it must additionally be taken into account, that a more sophisticated plant technology is needed (regarding fuel feeding, furnace, boiler, flue gas cleaning and ash disposal), which would result in considerably higher investment costs.

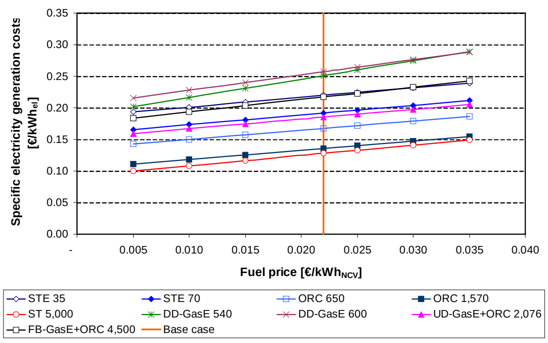

Figure 4: Influence of the fuel price on the specific electricity generation costs

4.2.3 Influence of the annual full load operating hours of the CHP unit

The influence of the annual full load operating hours of the CHP plants on the specific electricity generation costs is shown in Figure 5. It can be seen that the increase of the specific electricity generation costs below about 4,000 annual full load operating hours is substantial and must in any case be avoided. As a recommendation, a biomass CHP plant should achieve at least 6,000 annual full load operating hours. A correct dimensioning in dependence of the heat demand (annual utilisation line) is very important in this context.

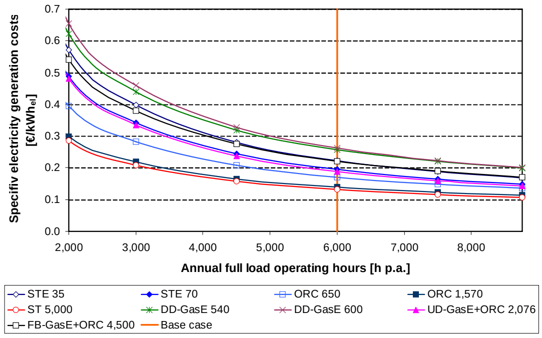

Figure 5: Influence of the annual full load operating hours on the specific electricity generation costs

A reduction of the annual full load operating hours of the CHP plants by 10% leads to an increase of the specific electricity generation costs between 6.5% and 8.8%. An increase of the annual full load operating hours by 10% leads to a decrease of the specific electricity generation costs between 5.4% and 7.2%.

5 CONCLUSIONS AND RECOMMENDATIONS

Within this study, five case studies of CHP plants based on biomass combustion and four case studies based on biomass gasification have been investigated.

With respect to the economy of the processes investigated, the investment costs, the fuel price and the annual full load operating hours have been identified as the most important influencing factors. The kind of biomass used and the respective fuel price have a strong influence on the economy. At least 6,000 annual full load operating hours are recommended for decentralised biomass CHP plants in heat controlled operation for an economic operation. Following, the correct design of such plants (base load coverage) according to the annual heat output line of the system is of utmost relevance.

The specific CHP related investment costs of the plants investigated based on biomass combustion amount to between 2,400 €/kW$_{el}$ (ST 5,000) and 5,300 €/kW$_{el}$ (STE 35). Their specific electricity generation costs (based on 6,000 annual full load operating hours) vary between 12.80 €Cent/kWh$_{el}$ (ST 5,000) and 21.95 €Cent/kWh$_{el}$ (STE 35). The gasification based processes investigated show specific CHP related investment costs between 4,100 €/kW$_{el}$ (UD-GasE+ORC 2,076) and 5,700 €/kW$_{el}$ (DD-GasE 600). Their specific electricity generation costs (based on 6,000 annual full load operating hours) vary between 18.53 €Cent/kWh$_{el}$ (UD-GasE+ORC 2,076) and 25.71 €Cent/kWh$_{el}$ (DD-GasE 600).

The specific investment costs as well as the electricity generation costs can significantly be reduced by a reduction of the investment costs or by investment subsidies.

In this context it is important to consider the cost reduction potential for the Stirling engine process by serial production. ORC processes have a certain cost reduction potential due to further technological development and by serial production (higher number of units of a certain size). However, this cost reduction potential is expected to be compensated by increasing raw material prices so that no net cost reduction potential exists. The steam turbine processes have no future cost reduction potential, because this technology has achieved a high state-of-the-art and is already produced in high numbers. All gasification based processes have a high cost reduction potential due to further technological development and serial production.

The economic calculations have shown, that the feed-in tariffs valid in Austria at present are usually not adequate to support and increase the number of biomass CHP plants based on biomass combustion below an electric capacity of about 1 MW$_{el}$ effectively. For CHP plants based on biomass gasification the feed-in tariffs currently valid in Austria are a completely insufficient support mechanism, as the specific electricity generation costs exceed by far the respective feed-in tariffs. Therefore, further market introduction of biomass CHP plants is currently hampered (especially in case of small electric capacities below 1 MW) and the technological development as well as demonstration of new technologies in Austria is suppressed.

Higher feed-in tariffs for green electricity, secured for a long period of time (at least 15 years) in combination with investment subsidies for highly innovative concepts are strongly recommended in order to promote the market introduction of biomass CHP plants both based on biomass combustion and biomass gasification, to contribute to the fulfilment of national and European targets concerning electricity generation from biomass and CO_2 reduction and to enforce and support new technological developments. Especially for small-scale CHP systems (< 1 MW$_{el}$) a stronger support is definitely needed. In this respect, a feed-in tariff regime similar to the German regulation (EEG) seams meaningful. Moreover, a lower limit for the overall annual efficiency of biomass CHP systems of at least 60% should be kept in order to ensure an efficient heat utilisation.

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