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FIRST STAGE ENVIRONMENTAL IMPACT ASSESSMENT OF A NEW HIGHLY EFFICIENT AND FUEL FLEXIBLE MEDIUM-SCALE CHP TECHNOLOGY BASED ON FIXED-BED UPDRAFT BIOMASS GASIFICATION AND A SOFC

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ABSTRACT: The EU Horizon 2020 project HiEff-BioPower (grant agreement No 727330, duration: 10/2016 – 09/2020) aims at the development of a new, innovative, fuel flexible and highly efficient medium-scale biomass CHP technology for a capacity range of 1 to 10 MW total energy output. It consists of (i) a fuel-flexible fixed-bed updraft gasifier, (ii) a novel compact gas cleaning system, (iii) a solid oxide fuel cell (SOFC) and (iv) a heat recovery system. The technology shall be applicable for a wide fuel spectrum (wood pellets, wood chips, SRC, selected agricultural fuels like agro-pellets, fruit stones/shells) and achieve high gross electric (40%) and overall (90%) efficiencies as well as equal-zero gaseous and particulate matter (PM) emissions. After the initial technical system design has been developed during the first project phase until 2018 (presented at EUBCE 2018), new preliminary experimental data has become available, as well as preliminary techno-economic analyses and market studies. Based on this new data, for the EUBCE 2019 conference this paper presents consecutive results from the first stage environmental impact assessment.
Keywords: combined heat and power generation (CHP), gasification, biomass, fuel cell, environmental impact assessment.

1 INTRODUCTION

As result of complex feedstock composition and heat integration, most combined heat and power (CHP) systems based on biomass fuels are realised only for medium and large-scale plants (typically 0.2 MWel up to more than 100 MWel). While mature technologies (e.g. steam turbine cycles or Organic Rankine Cycle processes) exist, major drawbacks of the current systems are their restricted fuel flexibility (especially regarding the utilisation of agricultural residues) as well as limited electric efficiencies (14 to 27%) [1]. Against this background the H2020 project HiEff-BioPower aims at the development of a new, innovative, fuel flexible and highly efficient medium-scale biomass CHP technology for a capacity range of 1 to 10 MW total energy output. It consists of (i) a fuel-flexible fixed-bed updraft gasifier, (ii) a novel compact gas cleaning system, (iii) a solid oxide fuel cell (SOFC) and (iv) a heat recovery system.

The technology shall be applicable for a wide fuel spectrum (wood pellets, wood chips, SRC, selected agricultural fuels like agro-pellets, fruit stones/shells) and achieve high gross electric (40%) and overall (90%) efficiencies as well as equal-zero gaseous and particulate matter (PM) emissions.

As in advance of any large-scale future deployment of new technologies, the potential environmental impacts have to be adequately assessed. Accordingly, the overall project methodology is divided into a technology development part (process simulations, computer aided design of the single units and the overall system, test plant construction, performance and evaluation of test runs, risk and safety analyses) and a related comprehensive technology assessment part covering techno-economic, environmental and overall impact assessments as well as market studies regarding the potentials for application. Detailed information about the initial technical system design in the first project phase until 2018 and further background can be found in [2].

This paper covers the preliminary impact assessment.

2 OBJECTIVES

The objectives of the environmental impact assessment are to estimate the effects an introduction of the new, fuel flexible CHP technology developed in the HiEff-BioPower (HEBP) project will have with major focus on European greenhouse gas (GHG) emissions and emissions of air pollutants.

Against the backdrop of ambitious GHG emission reduction goals, biomass solid fuel heating is often intended to be scaled up for taking a leading role in future low-carbon energy heating and power generation strategies. In light of the European Union's greenhouse gas emission reduction goal for 2030, namely at least 40% compared to 1990, using biomass to supply energy is seen as an important line of action to mitigate GHG emissions. The Green-X EUCO27 scenario developed for the European Commission foresees that biomass heat production will grow from 80 Mtoe in 2014 to 104 Mtoe in 2030 [3]. Concurrently, biomass energy demand for electricity generation is expected to increase from 14 Mtoe in 2014 to 24 Mtoe in 2030 [3]. Assessing how the new CHP technology developed in the HiEff-BioPower project will affect EU-wide GHG emissions compared to the respective GHG emissions of competing biomass and fossil fuel based technologies is one major objective of the impact assessment.

Parallel to mitigating GHG emissions the European Union aims to further improve air quality. In December 2016 the European Parliament and the Council of the European Union have passed an amended Directive on the reduction of national emissions of certain atmospheric pollutants (2016/2284/EU). With this legislation the European Union intends to take a major step towards its long-term goal of achieving a level of air quality that does not have significant negative impacts on and risks to human health and the environment. Solid fuel combustion in old and outdated installations has been identified as one of the main sources for particulate matter (PM) related ambient air pollution. While particulate matter is often distinguished by the size of the particles, for this impact assessment the particulate matter emissions are aggregated as total suspended particle (TSP) emissions. Other indicator pollutants impairing air quality are carbon monoxide (CO), organic gaseous compounds (OGC) and nitrogen oxides (NO_X).

Estimating how the new HiEff-BioPower CHP technology will affect EU-wide TSP, CO, OGC and NO_X emissions compared to competing state-of-the-art biomass and fossil fuel based technologies is another major objective of the environmental impact assessment.

A third objective of the impact assessment is to quantify fuel and grid electricity consumption of the new HiEff-BioPower CHP technology compared to existing technologies. These results are critical against the backdrop of security of supply as well as the sustainability criteria that biomass used for energy production has to fulfill according to the Directive on the promotion of the use from renewable sources (2018/2001/EU). Securing the supply of energy is another important pillar of the European Union's energy policy. General guidelines on how to achieve this have been laid down in the European Energy Security Strategy [4]. This strategy names a fuel-switch to indigenous renewable energies as an important approach. By being applicable for a wide fuel spectrum (wood pellets, wood chips, SRC, selected agricultural fuels like agro-pellets, fruit stones/shells) the HiEff-BioPower CHP is able to contribute to European energy security while at the same time making use of fuels that fulfill all sustainability criteria.

3 METHODOLOGY

The methodology used to prepare the impact assessment is derived from the Impact Assessment Guidelines of the European Commission [5], [6]. Four application cases have been identified for the HiEff-Biopower CHP:

- Application A1 encompasses "small" CHP systems (200 kW_{el} / 260 kW_{th}) for base load district heating or heat supply for large companies in Central Europe (Germany, Austria) with around 8,000 annual full-load operating hours and up to three start-up and shutdown cycles per year.
- Application B1 encompasses "small" CHP systems (200 kW_{el} / 260 kW_{th}) for base and medium load coverage (e.g. district heating, hotels, industry) in Central Europe (Germany, Austria) with around 5,000 annual full-load operating hours, 2,000 part-load operating hours, and up to twelve start-ups per year.
- Application A2 encompasses "large" CHP systems (1,000 kW_{el} / 1,300 kW_{th}) for base load district heating or heat supply for large companies in Central Europe (Germany, Austria) with around 8,000 annual full-load operating hours and up to three start-ups per year.
- Application B2 encompasses "large" CHP systems (1,000 kW_{el} / 1,300 kW_{th}) for base and medium load coverage (e.g. district heating, hotels, industry) in Central Europe (Germany, Austria) with around 5,000 annual full-load operating hours, 2,000 part-load operating hours, and up to twelve start-ups per year.

  For each application case different technologies and fuels could be utilised. Therefore, four technology scenarios are modelled for each application case. These are

- a wood chip biomass boiler + electricity from the grid scenario (BB_WC),
- a wood pellet gas engine scenario (GE_WP),
- the wood chip HiEff-BioPower CHP scenario (HEBP_WC),
- and the wood pellet HiEff-BioPower CHP scenario (HEBP_WP).

Both the BB_WC and the GE_WP scenarios assume the use of existing state-of-the-art technologies, while the HEBP_WC and HEBP_WP scenarios suppose the use of the new HiEff-Biopower CHP, albeit with different fuels (wood chips in the case of HEBP_WC, wood pellets in the case of HEBP_WP).

All scenario runs for each application case assume the same stock of appliances. For each year t the stock is calculated from the formula

$$stock_{i,t} = stock_{i,t-1} + sales_{i,t-1} - sales_{i,t-T-1},$$

where i refers to the application case and T signifies the technical lifetime. The sales for each year t are a result of the market study, and represent the technical sales potential for the full market segment that the HiEff-BioPower technology could address in future. The steps carried out to estimate this market potential were as follows: (1) estimation of the total current stock of CHP plants in the capacity range relevant for the HiEff-BioPower technology for the industry and district heating sectors, (2) assessment of the future market size according to the current stock, the renovation rates of the technologies, and the expected increase (or decrease) of the heat demand in each part of the market segment, and (3) estimation of the potential HiEff-BioPower sales in the future by considering the potential market shares of the technology compared to state-of-the-art biomass technologies providing heat and electricity (determined by a benchmarking analysis based on environmental and economic competitiveness).

The preliminary market study identified three different projections (high/medium/low) for the technical sales potential. This paper focuses on the medium projection exclusively.

The technical lifetime T is resulting from the techno-economic analysis. Decommissioned appliances are assumed to be replaced and lead to additional sales.

To attain the objectives discussed in the preceding section, the impact assessment model generates the following outputs (among others) for every year t until 2050, each technology scenario and each application case:

- GHG emissions in CO_2eq/year resulting from fuel and grid electricity consumption, respectively
- TSP, CO, OGC and NO_X emissions resulting from fuel and grid electricity consumption, respectively
- Fuel and grid electricity consumption

The heat demand differs between application cases, but is similar among the four technology scenarios for each application case. Furthermore, all scenarios suppose that the typical nominal output of appliances in Europe needs to decrease by about 2% per year as expected effect of improved insulation of the buildings due to the EU Energy Performance of Buildings Directive ("EPBD").

The amount of fuel necessary to meet the heat demand, the electricity production and the net grid electricity consumption, which may be negative, were derived during the techno-economic analysis for each technology scenario.

The impact assessment model calculates greenhouse gas and air pollutant emissions arising from fuel and grid electricity consumption. The emission intensities needed for this calculation were derived from the techno-economic analysis or taken from additional literature.

Following the general approach in the HiEff-Biopower project, all analyses are performed in two phases. At an early stage of the project a preliminary techno-economic analysis has been performed, which was based on inputs from the manufacturing partners regarding expected investment and operation costs as well as on experiences from the scientific partners regarding the expected performance data and emissions.

The defined parameters have been compared with available data from comparable state-of-the-art CHP systems.

The emissions of the HiEff-BioPower CHP plant considered (see Table) are based on experiences with product gases from updraft gasifiers, the expected efficiency of the gas cleaning unit foreseen and the fact that nitrogen compounds in the product gas are almost completely converted in the SOFC system to N_2 (practically no NO_x emissions) as well as the catalytic SOFC afterburner almost fully oxidises CO and hydrocarbons [10]. The emissions of the state-of-the-art technology BB_WC are based on the emission limits according to the Austrian labelling UZ37 for wood chip boilers [10], while the emissions regarding the GE_WP are referred to the emission limits according to the German "Technical Instructions on Air Quality Control" [10] for gas engines. The annual utilisation rates of the technologies investigated are based on manufacturer specifications and under consideration of real life operation behaviour (part load operation, start-up, shutdown, and malfunctions).

This preliminary evaluation supports the ongoing technology development and optimisation work and provided relevant input data for the first stage impact assessment.

At a later stage, based on updated economic data and on the results of test runs performed within the project (regarding efficiencies and emissions), the final techno-economic analyses will be performed. They shall define the constraints and demands for the final system design to assure the development of a technically as well as economically viable solution.

The greenhouse gas emission intensities for the fuels take life cycle emissions into account. In the case of grid electricity, a decrease of the emission intensity is to be expected. The GHG emission intensity of grid electricity and its development in the future has been taken from the EU Ecodesign Impact Accounting [10].

4 RESULTS ACHIEVED SO FAR

4.1 Development of sales and stock

The sales reported in Figure 1 are total sales, i.e. they include also sales that replace decommissioned end-of-life systems. Based on this input, stock data for the impact assessment is further calculated with a sales-driven stock model. To compare the potential total impact corridor of the different technologies considered for the relevant market segment, in the following it is assumed that all sales are taken over by one or the other technology.

For the purposes of a preliminary impact assessment, stocks of new systems are calculated from a defined reference year (2020) onwards. This reference year will be adapted for the final impact assessment with realistic assumptions for a future market introduction, based on the final outcomes of the technology development at the end of the project. In short, potential historical stocks are not carried over, and the model then combines total sales data from the reference year onwards with average lifespans characteristic for each application to calculate stock data successively for each year of the simulation period, using the equation presented in the preceding section.

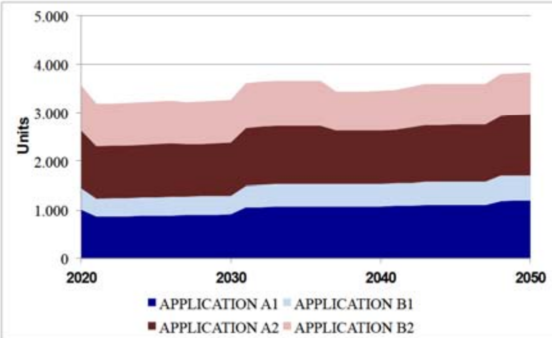

Figure 1: Development of sales for the four application cases until 2050

Figure 1 and Figure 2 show that for the considered cases, applications A1 and A2, closely followed by application B2, dominate the market in sheer number of potential sales and consequently in stock sizes. Sales dynamics are similar in all applications with variability stemming from assumptions made on historical sale patterns in the market study. Cumulative sales lead to stocks increasing at a steady growth rate until about 18-20 years after the reference year, when the growth rate strongly decreases because from that point onwards the sales do not solely add to the stock of new systems but also come to replace end-of-life systems installed after the reference year. Stock levels reach 19,846 units in application A1 and 21,094 in application A2 in 2050. Application B1 and B2 technology stocks reach 9,407 and 17,277 units in 2050, respectively.

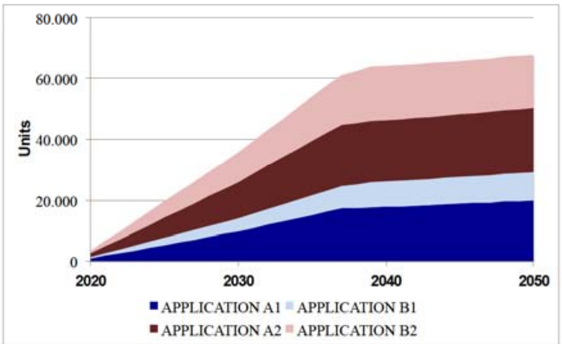

Figure 2: Development of the stock for the four application cases until 2050

4.2 Greenhouse gas emissions

As described in the preceding section, GHG emissions are calculated by multiplying fuel and net grid electricity consumption with the respective emission intensities. Table shows the fuel emission intensities used for modelling. Average EU-28 GHG emissions of electric power generation are assumed to decrease from 0.40 kg CO_2/kWh$_{el}$ in 2015 to 0.26 kg CO_2/kWh$_{el}$ in 2050 [9]

Table I: GHG emission intensities fuels

		Wood chips	Wood pellets
GHG	kg CO_2eq/GJ	4	11

Source: [10]

Four technology scenarios are considered for each application: HiEff-BioPower technologies fuelled with wood chips or wood pellets (HEBP_WC, HEBP_WP), a gas engine fuelled with wood pellets (GE_WP), and a wood chip biomass boiler (BB_WC).

The scenarios with the new HiEff-BioPower technology using wood chips or wood pellets help to save more GHG emission than scenarios with the state-of-the-art conventional wood chip boiler and the gas engine.

Avoided grid electricity GHG emissions are five to six times higher than direct emissions from fuel combustion for HiEff-BioPower with wood pellets, and 13-15 times higher for HiEff-BioPower with wood chips.

The difference comes from the fact that the wood pellets, as a more processed fuel, have a higher GHG intensity than wood chips.

Emissions from fuel combustion dominate total GHG emissions for the wood chip boiler in all applications (61-63% in 2050, depending on the application). This technology scenario (because it does not displaces grid electricity generation) also shows consistently higher emissions than the other technologies. For the gas engine, avoided grid electricity GHG emissions are 4.5 to 5 times higher (in absolute value) than the direct GHG emissions from wood pellets combustion.

The gas engine technology fuelled with wood pellets helps to avoid (through displaced grid electricity generation) about 85-90% of the amount of GHG emissions in 2050 that the HiEff-BioPower technologies would help to avoid. The wood chip biomass boiler generates (mostly directly through fuel combustion) about 10% of the GHG emissions that the HiEff-BioPower systems help to avoid.

Regarding sales and stock volumes, applications A1 and A2, closely followed by application B2, dominate the market potentials. Applications A2 and B2, however, consist of larger systems (with higher thermal output) than A1 and B1. In addition, application A2 registers 8,000 full load hours against 5,000 for application B2 (plus 2,000 part load hours). These underlying aspects of the model amplify the differences in potential market sizes when comparing the emission scenarios between applications.

Among the application cases, application A2 presents the highest GHG emission levels and emission savings (depending on the technology) in 2050 for all technologies considered (see Figure 3). Application B2, whose emission savings reach around 44% (HEBP_WP) to 47% (HEBP_WC, GE_WP) of that in application A2, for the same technologies. The wood chip boiler scenario in application B2 is responsible for 53% as much emissions in 2050 as the same technology scenario in application A2.

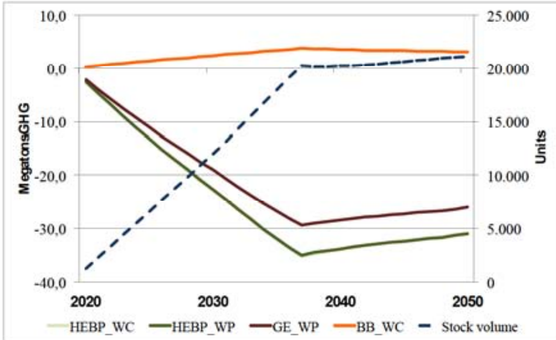

Figure 3: GHG emissions in the four technology scenarios for Application A2

The smaller systems in application A1 (but with the same 8,000 full load hours as in application A2) generate 19% of the emission levels and savings in application A2, consistently across technologies and types of emissions.

Finally, application B1, characterised by the lowest market potential, small systems, and lower full load hours, reaches around 5% of the emission levels and savings in application A2.

For each application an additional graph shows in detail the contributions of fuel use and net grid electricity consumption in generating GHG emissions in the corresponding scenario. The terms "fuel" in the graphs refers to direct emissions resulting from biomass fuel use by the HiEff-BioPower systems. The term "grid" indicates net emission effects from grid electricity generation (i.e. emissions from grid electricity actually consumed by the application case minus avoided emissions through the system's own gross electricity output). As an example, Figure 4 shows the detailed GHG emissions for the HEBP_WP scenario for application A2.

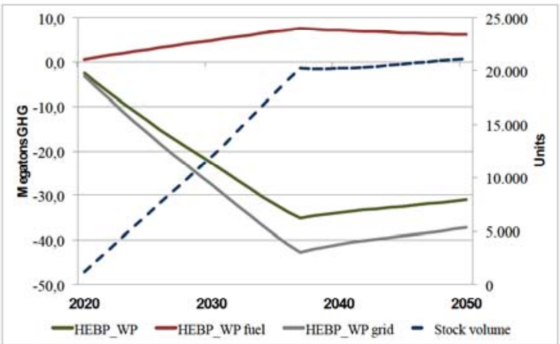

Figure 4: Detailed GHG emissions for the HEBP_WP scenario for Application A2

4.3 Air pollutant emissions

Air pollutant (i.e. TSP, CO, OGC and NO_X) emissions are calculated by multiplying fuel and net grid electricity consumption with the respective emission intensities. Table presents the air pollutant emission intensities for the four technology scenarios BB_WC, GE_WP, HEBP_WC and HEBP_WP.

Table II: Air pollutant emission intensities for the technology scenarios

		BB_ WC	GE_ WP	HEBP_ WC	HEBP_ WP
TSP	mg/MJ	25	7	0	0
CO	mg/MJ	120	333	20	20
OGC	mg/MJ	4	0	0	0
NO_X	mg/MJ	100	167	0	0

Source: HEBP techno-economic analysis

The emission intensities for grid electricity can be found in Table. Due to missing data and according to [10], air pollutant emission intensities had to be assumed to remain constant until 2050 for the preliminary impact assessment.

Table III: Air pollutant emission intensities for grid electricity

		grid electricity (EU-28)
TSP	g/kWh	0.04
CO	g/kWh	0.14
OGC	g/kWh	0.02
NO_X	g/kWh	0.47

Source: Own calculation based on EEA data

Total TSP, CO, OGC, and NO_X emissions are the result of contributions from solid fuel combustion and net electricity consumption. The latter means that emissions from grid electricity consumption are calculated as the difference between emissions from grid electricity actually consumed in each scenario and from grid electricity avoided through the gross electricity output of these systems. As a result net emissions from grid electricity consumption may be even negative, which indicates avoided grid electricity emissions.

In short, negative net emissions for HiEff-BioPower scenarios, in particular, result from vastly less emission intensive technologies (less fuel related emissions) further compensated by avoided emissions from traditional grid electricity generation. The HiEff-BioPower systems show negative net emissions, except for CO where direct emissions from fuel combustion and avoided emissions from electricity generation approximately compensate one another. Direct and avoided indirect TSP emissions also almost cancel out in the gas engine scenarios. For this technology, OGC net emissions are negative while CO and NO_X emissions are positive, higher than and comparable to that of the wood chip boiler, respectively. In any case, the new HiEff-BioPower technology scenarios show significant technical emission saving potentials compared to state-of-the-art conventional biomass boilers and gas engine CHP. These preliminary results are sensitive to crucial technical parameters such as emission intensity of the different solid fuels used by different technologies.

Further assumptions regarding the future development of grid electricity emission intensity and heat energy demand (driving thermal output, hence fuel requirements) are also very relevant for the overall behaviour of the model.

Independent of the application case or technology and all other aspects being equal, total stock emissions decrease in the long run when the stock's growth rate decreases or plateaus. This can be explained by the assumption that the typical size of systems in Europe decreases by 2% per year as expected effect of improved insulation and energy performance of buildings (based on EPBD, the European Performance of Buildings Directive). This rate then happens to be higher than the slowing rate of stock growth. Consequently, this means less fuel input, hence less fuel related emissions.

According to the preliminary impact assessment results, Application A2 presents the highest emission levels and emission savings (depending on the technology) for all technologies and types of emission considered. Application B2 comes in second. Third are the smaller systems in application A1 (but with the same 8,000 full load hours as in application A2). Finally, application B1, characterised by the lowest market potential, small systems, and lower full load hours, reaches only a fraction of the emission levels and savings observed in application A2. This follows from the sales and stock volumes where applications A1 and A2, closely followed by application B2, dominate the market potentials. Applications A2 and B2, however, consist of larger systems (with higher thermal output) than A1 and B1. In addition, application A2 registers 8,000 full load hours against 5,000 for application B2 (plus 2,000 part load hours). These underlying aspects of the model amplify the differences in potential market sizes when comparing the scenarios between applications.

Consequently, the scenario results with focus on application A2 will be discussed more in detail. The scenarios with the new HiEff-BioPower technology using wood chips or wood pellets present significantly lower emission levels (for all four emission types) than scenarios with the state-of-the-art conventional wood chip boiler and gas engine. The emission totals presented in the graphs below are the net sums of direct emissions from fuel combustion in the heating or CHP systems and indirect emissions from (EU-average) grid electricity generation.

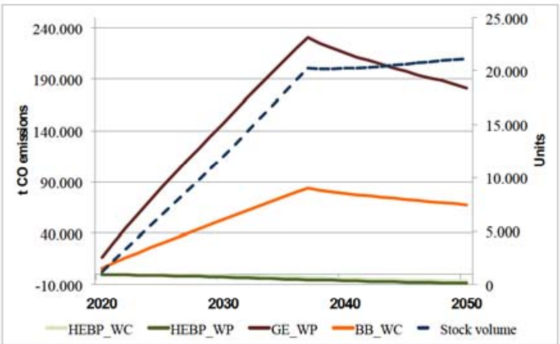

Figure 5: CO emissions in the four technology scenarios for Application A2

In all non-GHG emission categories, emissions from fuel combustion dominate the totals for the wood chip boiler (at least 97% in 2050). This technology scenario also shows consistently higher emissions than with the gas engine, except for CO emissions. Emissions from fuel combustion (here wood pellets) dominate the net totals for the gas engine for CO (Figure 5) and NO_X.

Avoided grid electricity emissions reach 9% and 60% of the actual fuel combustion-related emissions (in absolute value) for CO and NO_X, respectively.

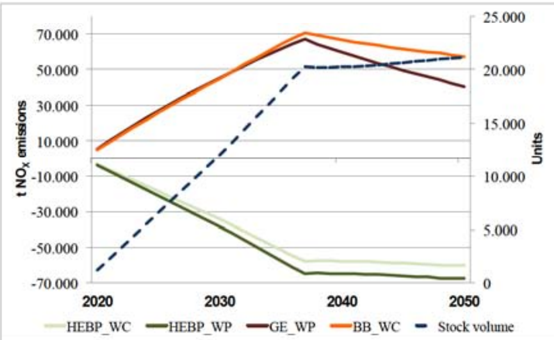

Figure 6: NO_X emissions in the four technology scenarios for Application A2

In the case of TSP (Figure 7), direct emissions from fuel combustion and avoided indirect emissions from grid electricity generation approximately compensate one another at first, but eventually avoided grid electricity emissions end up about 28% higher (in absolute value) than fuel emissions in 2050. In the case of OGC emissions (Figure 8), the avoided indirect emissions entirely dictate the position of the curve in the negative part of the graph.

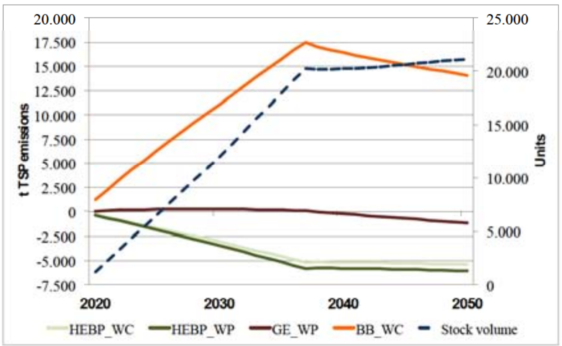

Figure 7: TSP emissions in the four technology scenarios for Application A2

The gas engine technology fuelled with wood pellets helps to avoid (through displaced grid electricity generation) 88% of the amount of OGC emissions in 2050 that the HiEff-BioPower technology (also fuelled with wood pellets, the ratio is 99% with wood chips) would help to avoid. The ratio goes down to around 20% for TSP emissions. The gas engine scenario is responsible for net positive emissions for CO and NO_X emissions, up to about 21-27 times higher (in absolute value) than the amount of emissions avoided with the HiEff-BioPower technology in the case of CO emissions in 2050.

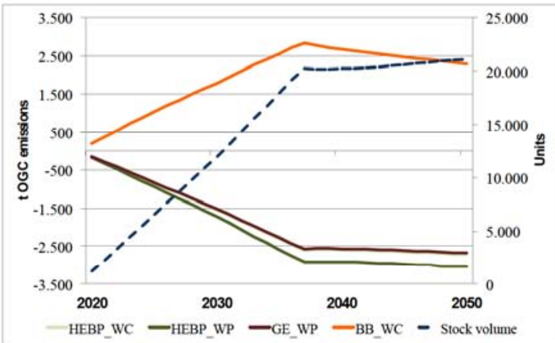

Figure 8: OGC emissions in the four technology scenarios for Application A2

The wood chip biomass boiler generates (mostly directly through fuel combustion) about as much OGC and NO_X emissions as the HiEff-BioPower systems help to avoid. The ratio goes up to almost three times and close to ten times as much emissions generated by the wood chip boiler as saved by the new HiEff-BioPower technology for TSP and CO emissions, respectively.

4.4 Fuel and grid electricity consumption

Using and converting energy efficiently is among the most important goals of the European Union's energy policy. The various technologies analysed in the impact assessment differ with respect to their total annual efficiency. Table shows the total annual efficiency for the different technologies and application cases.

Table IV: Total annual efficiency for the different technologies and application cases

	BB_WC	GE_WP	HEBP_ WC	HEBP WP
Application A1	81%	76%	81%	81%
Application A2	81%	76%	81%	81%
Application B1	81%	74%	79%	80%
Application B2	81%	74%	79%	80%

Source: HEBP techno-economic analysis

The total annual efficiency determines the fuel consumption seen in the technology scenarios. Results for the total fuel consumption of applications A1, B1, A2, and B2 follow each application's and technology's stock dynamics. In all four applications, fuel consumption first increases with the growing stock of appliances. It then starts to decrease, around 2038 for application A1 and A2 and around 2040 for applications B1 and B2, due to the different technical lifetimes assumed for the corresponding technologies. The rate of stock growth starts decelerating at those periods because new systems not only add up to the stock but also replace end-of-life systems that were installed after the reference year. The decrease of fuel consumption seen then can be explained by the assumption that the typical size of heating systems in Europe decreases by 2% per year as expected effect of improved insulation of the buildings (based on EPBD).

This rate then happens to be higher than the slowing rate of stock growth, resulting in lower fuel input in absolute terms.

Based on the available input data, the calculated solid fuel consumption in 2050 is highest for application A2, followed by applications B2, A1, and B1.

Figure 9 depicts the development of fuel consumption until 2050 in the four technology scenarios for application A2.

Application A2 also has the largest stock of installed systems in 2050, followed by A1 and B2 (in that order).

Applications A2 and B2 consist of larger systems (with higher thermal output) than A1 and B1. In addition, applications A2 and A1 register 8,000 full load hours against 5,000 for application B2 and B1 (plus 2,000 part load hours). The size of the systems explains why application B2 scenarios require more fuel than application A1 scenarios. Further investigations and comparisons are needed at a later stage of the project to properly assess the relevance of this result for security of supply and the management of limited biomass resources in Europe.

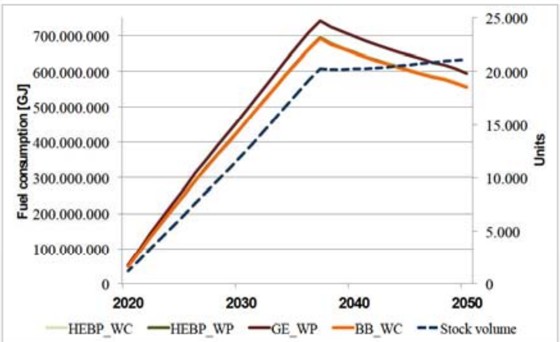

Figure 9: Fuel consumption in the four technology scenarios for Application A2

Comparing the technology scenarios with one another, within an application and across applications, mainly requires looking at respective total annual efficiencies and thermal outputs. In all applications, the wood chip boiler presents the lower overall fuel use, which is to be expected because the technology consistently has the highest annual efficiency combined with the lowest thermal output. The level of fuel use for the HiEff-BioPower technology scenarios is virtually indistinguishable from that of the wood chip boiler in applications A1 and A2, it is a mere 2% higher in applications B1 and B2 in 2050, due to slightly lower annual efficiencies and higher thermal output levels. The gas engine scenarios require in 2050 7% to 9% more fuel (wood pellets) than the wood chip boiler scenarios in applications A1 and A2 as well as B1 and B2, respectively. The gas engine technology has the same level of thermal output as the wood chip boiler across all applications but a lower total annual efficiency level.

The results of the impact assessment for grid electricity consumption present another picture. For the wood chip boiler scenarios the grid electricity consumption is equal to the (limited) amount of electricity that the boiler requires for own function plus the electricity tapped from the grid to satisfy the power needs in application cases A1, B1, A2, and B2. For the gas engine and HiEff-BioPower CHP scenarios net grid electricity consumption is the difference between gross electricity production of the system and the electricity needs of the corresponding technology scenario.

In all applications, the HiEff-BioPower technologies present a higher gross electricity production than the gas engine. The HiEff-BioPower scenarios also have higher electricity consumption levels than the gas engine scenario. The HiEff-BioPower technology fuelled with wood pellets consistently has a higher gross electricity production than the wood chip version, with the same level of electricity consumption. In the end, the HiEff-BioPower scenario using wood pellets still feeds more electricity to the grid than the gas engine. This can be seen in Figure 10**,** which shows the grid electricity consumption in the four technology scenarios for application A2. The orange curve depicting grid electricity consumption for the HEBP_WP scenario has lower grid consumption values (i.e. is "more negative") than any other scenario. In other words, the HiEff-BioPower scenario with wood pellets displaces more grid electricity through its own production than the other scenarios. The differences in gross electricity production and electricity consumption between HiEff-BioPower with wood chips and gas engine cancel out so that the net electricity consumption curves are practically indiscernible from one another.

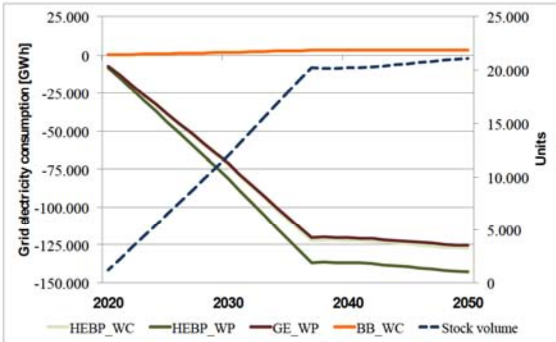

Figure 10: Grid electricity consumption in the four technology scenarios for Application A2

The absolute net electricity consumption values reflect the systems' and stock sizes. A2 and B2 applications use large systems, with more full load hours in A2. Application B1 uses small systems, coupled to the smallest stock size.

5 SUMMARY, CONCLUSIONS AND OUTLOOK

This paper presents results of the preliminary impact assessment and therefore – as the name indicates – also a preliminary assessment of the use phase environmental performance of the HiEff-BioPower CHP under development.

Four application cases for space heating and domestic hot water supply are investigated: application A1 encompasses "small" CHP systems (200 kW_{el} / 260 kW_{th}) for base load district heating or heat supply for large companies in Central Europe (Germany, Austria) with around 8,000 annual full-load operating hours and up to three start-ups per year, application B1 encompasses "small" CHP systems (200 kW_{el} / 260 kW_{th}) for base and medium load coverage (e.g. district heating, hotels, industry) in Central Europe (Germany, Austria) with around 5,000 annual full-load operating hours, 2,000 part-load operating hours, and up to twelve start-ups per year, application A2 encompasses "large" CHP systems (1,000 kW_{el} / 1,300 kW_{th}) for base load district heating or heat supply for large companies in Central Europe (Germany, Austria) with around 8,000 annual full-load operating hours and up to three start-ups per year, application B2 encompasses "large" CHP systems (1,000 kW_{el} / 1,300 kW_{th}) for base and medium load coverage (e.g. district heating, hotels, industry) in Central Europe (Germany, Austria) with around 5,000 annual full-load operating hours, 2,000 part-load operating hours, and up to twelve start-ups. Furthermore, two variants of the new HiEff-BioPower systems technology (fuelled with wood chips and with wood pellets, respectively) are compared to a state-of-the-art conventional biomass boiler fuelled with wood chips, and a state-of-the-art CHP gas engine system fuelled with wood pellets. The analysis includes yearly as well as cumulated effects of putting these four technologies on the entire European market until 2050. Thereby, emissions (GHG, TSP, CO, OGC, NO_X) and fuel and net grid electricity consumption have been taken into account.

As the Impact Assessment relies on preliminary input data, all IA results are also preliminary. Many assumptions and parameters are likely to be updated in the course of the technical development in the HiEff-BioPower project. Therefore, all absolute quantities (of emissions, fuel consumption etc.) presented in this report should be interpreted accordingly. Especially relevant and useful at this stage was to understand the dynamics of the different application cases to be analysed and their sensitivities to technical parameters and other modelling assumptions. This kind of reasoning will inform both future development of the impact assessment tools and support decision-making regarding the general direction of the technology development.

The modelling results help to identify the main emission drivers for the different technologies considered. In all CHP technology scenarios (HiEff-BioPower and gas engine), greenhouse gas emissions are driven by grid electricity consumption and since these technologies generate their own electricity, use part of it but feed most of it to the grid, avoided emissions from grid electricity quickly overcompensate direct GHG emissions from fuel use in these scenarios, meaning that net GHG emissions are actually negative. In the wood chip boiler scenario, on the other hand, greenhouse gas emissions are mainly driven by fuel consumption.

Regarding CO, OGC, TSP and NO_X emissions, whether solid fuel combustion or indirect emissions from grid electricity generation is the main driver depends on the technology and the type of emissions. The HiEff-BioPower systems show negative net emissions, except for CO where direct emissions from fuel combustion and avoided emissions from electricity generation compensate one another. Direct and avoided indirect TSP emissions also almost cancelled out in the gas engine scenarios. For this technology, OGC net emissions are negative while CO and NO_X emissions are positive, higher than and comparable to that of the wood chip boiler, respectively. In any case, the new HiEff-BioPower technology scenarios show significant technical emission saving potentials compared to the state-of-the-art conventional biomass boilers and gas engine CHP. These preliminary results are sensitive to crucial technical parameters such as emission intensity of the different solid fuels used by different technologies. Further assumptions regarding the future development of grid electricity emission intensity and heat energy demand (driving thermal output, hence fuel requirements) are also very relevant for the overall behaviour of the model.

Regarding sales and stock volumes, applications A1 and A2, closely followed by application B2, dominate the market potentials. Applications A2 and B2, however, consist of larger systems (with higher thermal output) than A1 and B1. In addition, application A2 registers 8,000 full load hours against 5,000 for application B2 (plus 2,000 part load hours). These underlying aspects of the model amplify the differences in potential market sizes when comparing the emission scenarios between applications. Application A2 presents the highest emission levels and emission saving potentials (depending on the technology) for all technologies and types of emission considered. Application B2 comes in second. Third are the smaller systems in application A1 (but with the same 8,000 full load hours as in application A2). Finally, application B1, characterised by the lowest market potential, small systems, and lower full load hours, reaches only a fraction of the emission levels and saving potentials observed in application A2.

Considered together, all the insights gained give some meaningful indications on the most prominent aspects to be considered for the further long-range HiEff-BioPower system design. Were the market potentials for the large systems (applications A2 and B2) to be fulfilled, any improvement in the HiEff-BioPower design could have further significant positive environmental effects. This preliminary impact assessment is then to be updated with new data from the second phase of the HiEff-BioPower project.

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8 LOGO SPACE