Early-stage LCA of a novel fuel flexible CHP technology based on biomass gasification and a SOFC

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Abstract
To mitigate climate change and reduce the consumption of fossil fuels, more efficient energy production is necessary. Combined heat and power systems (CHPs) are a key technology to reach such an objective, due to its higher energy efficiency than the separate production of heat and electricity. These environmental benefits can be enhanced by using a versatile energy source, such as biomass. The H2020 Hieff-BioPower project is developing an innovative medium-scale biomass CHP technology based on biomass gasification combined with solid oxide fuel cells (SOFC). This technology shall reach a high gross electric and overall energy efficiencies (40% and 90% respectively) and is expected to achieve equal-zero gaseous and PM emissions. This study analyses the expected environmental performance of producing heat and electricity with such a technology, using environmental Life Cycle Assessment (LCA). The analysis investigates the cradle-to-gate impacts considering different biomass feedstocks and including the manufacturing of the main power plant components (gasifier, gas cleaning unit, SOFC). The preliminary results indicate environmental improvements when compared with state of the art technologies such as internal combustion engines and organic Rankine cycle CHPs.
Keywords: LCA, biomass, CHP, Gasification, SOFC

1. Introduction

Novel combined biomass heat and power systems (CHPs) are necessary to mitigate climate change and reduce the consumption of fossil fuels. In particular, CHP plants are very effective in process industries that require large amounts of both heat and power in their production activities (Philipp et al., 2016). When biomass is used as fuel, the energy savings of a CHP technology can be supplemented by further benefits such as greenhouse gas (GHG) emissions savings and reduction of the depletion of fossil fuels (Adams and McManus, 2014). This study provides an early stage life cycle assessment (LCA) on an innovative fuel flexible and highly efficient medium-scale biomass CHP technology combining gasification and a Solid Oxide Fuel Cell (SOFC) launched by the H2020 project HiEff-BioPower (Brunner et al., 2018). The goal of the LCA is to estimate the environmental performance of this new technology and find environmental hotspots. Moreover, the potential environmental impacts of the analysed technology were compared with the current biomass-CHP benchmark technologies i.e. gas engines (GE) and Organic Rankine Cycle (ORC) CHPs (Brunner et al., 2018). This comparative analysis, in case of a positive result, might promote further development and future commercialization of the HiEff-BioPower technology.

2. Models and Methods

In the novel biomass SOFC CHP technology, the biomass feedstock is fed into a gasification reactor and converted into syngas. This syngas needs to be purified in a gas cleaning unit (GCU) before being used by the fuel cell. The cleaned product gas is then converted into electricity in a SOFC fuel cell of 199 kWe power. The off-gases of the SOFC fuel cell are then burned in a catalytic afterburner. From the resulting flue gases, heat is recovered (Brunner et al., 2018). This technology shall reach a gross electric efficiency of 40%, and overall energy efficiency of 90%, and is expected to achieve equal-zero gaseous and PM emissions. The HiEff-BioPower technology can be fed with softwood pellets, industrial wood chips, forest wood chips, miscanthus pellets, and olive stones. In this study, only wood chips (market mix made of industrial and forest wood chips) and miscanthus pellets were investigated (Brunner et al., 2018).

The environmental assessment was performed following an attributional LCA approach. Since the system provides two different functions, namely the supply of heat and power, two functional units were defined: 1 MJ of heat and 1 kWh of electricity. Allocation of impacts to each function was performed considering the exergy content of each product, estimated through the Carnot factor. For the calculation of the Carnot factor, it was assumed a reference temperature of 25°C and a heat supply temperature of 90°C. The following environmental categories, which are relevant when energy is produced from biomass (Broeren et al., 2017), were selected following the ILCD 2011 method: Climate Change (CC), Photochemical ozone formation (POF), Particulate matter (PM), Acidification (AC), Terrestrial eutrophication (TE), Mineral, fossil and renewable resource depletion (MFRD) and Water resource depletion (WRD). Inventory data for wood chips have been retrieved from Ecoinvent 3.4 while the cultivation of Miscanthus and the subsequent processing into pellets were adapted from the paper by Peric et al. (2018). Inventory data for manufacturing (e.g. type and amount of steel required in component) and maintenance (e.g. replacement of the stack) are based on internal project data while data for SOFC manufacturing, and its balance of system, was taken from Rillo et al. (2017).

3. Results and Conclusions

The breakdown of environmental impacts for the Hieff-BioPower technology operating with wood chips are shown in Figure 1. The production of the biomass feedstock can be identified as the main environmental hotspot. The impact of maintenance and manufacturing stages are also important when operating with wood chips. Such impact is mainly caused by the manufacturing and replacements of the SOFC. In the case of Mischantus pellets, whose production is more impacting than wood chips, the impact is dominated by the production of Mischantus pellets which represents 72-99% of the total impact.

Figure 1. Breakdown of the characterized environmental impacts (%) of producing energy with wood chips (independent on functional unit).

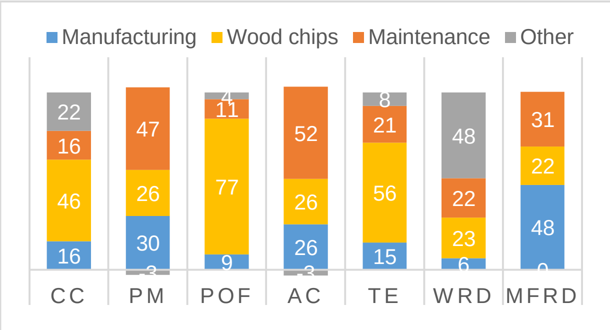

Table 1. Environmental characterized impacts per 1 MJ of heat

Imp. Cat.	Unit	HWC	HMP	GE	ORC
CC	kg CO2 eq	1.7E-03	5.6E-03	8.7E-03	2.6E-03
PM	kg PM2.5 eq	1.2E-06	3.7E-06	1.3E-05	1.4E-04
POF	kg NMVOC eq	1.3E-05	2.2E-05	2.9E-05	1.7E-04
AC	molc H+ eq	1.4E-05	4.0E-05	4.0E-04	1.2E-04
TE	molc N eq	2.3E-05	9.8E-05	1.7E-03	6.4E-04
WRD	m3 water eq	4.7E-06	2.9E-04	1.2E-04	2.2E-06
MFRD	kg Sb eq	1.5E-07	4.8E-07	3.2E-06	9.3E-08

Table 1 and Table 2 show the total characterized impacts of both HiEff-BioPower scenarios compared with other biomass-CHPs (a GE with biogas from biowaste/sewage sludge and a ORC with wood chips), for both heat and electricity functional units. Both datasets were retrieved from Ecoinvent database.

The comparison indicates that the Hieff BioPower technology operating with woodchips has the best environmental performance compared to all the assessed technologies. When the system is fed with an energy crop as miscanthus pellets, the Hieff BioPower technology is still environmentally competitive to the other technologies. However, GE and ORCs offer better performances in several impact categories (GEs are better in WRD while ORCs are better for CC, WRD and MFRD).

Table 2. Environmental characterized impacts per 1 kWh of electricity

Imp. Cat.	Unit	HWC	HMP	GE	ORC
CC	kg CO2 eq	3.4E-02	1.1E-01	1.8E-01	5.6E-02
PM	kg PM2.5 eq	2.4E-05	7.4E-05	2.7E-04	3.0E-03
POF	kg NMVOC eq	2.7E-04	4.5E-04	6.2E-04	3.6E-03
AC	molc H+ eq	2.8E-04	8.0E-04	8.5E-03	2.5E-03
TE	molc N eq	4.6E-04	2.0E-03	3.6E-02	1.4E-02
WRD	m3 water eq	9.4E-05	5.8E-03	2.6E-03	4.6E-05
MFRD	kg Sb eq	3.1E-06	9.7E-06	6.7E-05	2.0E-06

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