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Aspects of using biomass as energy source for power generation

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Abstract. *Biomass represents an important source of renewable energy in Romania with about 64% of the whole available green energy. Being a priority for the energy sector worldwide, in our country the development stage is poor compared to solar and wind energy. Biomass power plants offer great horizontal economy development, local and regional economic growth with benefic effects on life standard. The paper presents an analysis on biomass to power conversion solutions compared to fossil fuels using two main processes: combustion and gasification. Beside the heating value, which can be considerably higher for fossil fuels compared to biomass, a big difference between fossil fuels and biomass can be observed in the sulphur content. While the biomass sulphur content is between 0 and approximately 1%, the sulphur content of coal can reach 4%. Using coal in power plants requires important investments in installations of flue gas desulfurization. If limestone is used to reduce SO_2 emissions, then additional carbon dioxide moles will be released during the production of CaO from $CaCO_3$. Therefore, fossil fuels not only release a high amount of carbon dioxide through burning, but also through the caption of sulphur dioxide, while biomass is considered CO_2 neutral. Biomass is in most of the cases represented by residues, so it is a free fuel compared to fossil fuels. The same power plant can be used even if biomass or fossil fuels is used as a feedstock with small differences. The biomass plant could need a drying system due to high moisture content of the biomass, while the coal plant will need a desulfurization installation of flue gas and additional money will be spent with fuel purchasing.*

Keywords: combustion, energy, fossil fuels, biomass, sulfur content.

Introduction

The products or waste that can be defined as biomass are varied as physical structure and chemical composition, therefore a widely accepted definition of biomass is used. United Nations Framework Convention on Climate Change (UNFCCC) define biomass in a specific and scientific way, as: "*Biomass means non-fossilized and biodegradable organic material originating from plants, animals and micro-organisms. This shall also include products, byproducts, residues and wastes from agriculture, forestry and related industries as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes. Biomass also includes gases and liquids recovered from the decomposition of non-fossilized and biodegradable organic material.*" (EB 20 Report, 2005). This definition of biomass leads to its big potential as renewable source and worldwide coverage. Actually there are such energy sources with precise time availability compared to other renewable energy sources that are conditioned by solar irradiance or wind speed.

According to the researchers from FINEX, Romania's biomass potential is about 318,000 TJ, equivalent to 7.6 million tons oil equivalent (TOE)/year. Biomass has the biggest energy potential in Romania, as a renewable source but it is underexploited. The biggest biomass resource is represented by vegetal residues from agriculture with a quota of 63%, followed by wood residues from forest exploitations of about 16%. The

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rest of 21% of biomass sources is represented by wastes from livestock farms, urban household wastes, and wood waste and sawdust with a share from total of 8%, 7%, and 6%, respectively (FINEX).

Agriculture provides important alternative biomass fuels. The most common sources of biomass provided by agriculture are: the energy crops (e.g. willow, poplar, switchgrass, Miscanthus), agricultural residues (e.g. straw from wheat, barley, rice, oat; stalks from corn, sunflower, rape, soya; cakes from rape or sunflower; any other residues as: sunflower shell, corn cobs, corn stover), and the biomass used to produce oils, methylesters and ethanol (AGROPOWER).

According to EUROSTAT, Romania produced 19,286 thousands of tons of cereal in 2015. Almost 9 millions of tons of corn were produced, representing 41.25% of all cereal production in Romania. Corn production is followed by wheat (7,955 thousands of tons), and barley (1,623 thousands of tons). Also, according to EUROSTAT, Romania produced in 2015, among the cereals, 6,371 thousands of tons of different agricultural crops, of which 919 thousands of tons of rape and turnip rape seeds, and 1786 thousands of tons of sunflower seeds. If we consider the grain straw proportion for wheat and barley of 1/0.8, for corn of 1/1.3, for sunflower of 1/4.1, and for rape seed of 1/2.9, respectively (AGROPOWER), we can assume that straw production in 2015 in Romania was about 6,364 thousands of tons of wheat straw, 1,298 thousands of tons of barley straw, 11,700 thousands of tons of corn stover, 4,377 thousands of tons of sunflower stalks, and 2,665 thousands of tons of rape stalks, respectively. Thus, only the main agricultural residues sum up more than 26 millions of tons of potential biomass fuel.

Forest is an important provider of woody biomass. In Romania, forests cover 6.5 million hectares, almost 30% of the country surface (ROMSILVA; IFN). Forests exploitation can reach annual 16-17 million cubic meters of wood mass, which could be used as biomass (ROMSILVA; IFN).

Besides the advantage that it is not influenced by the weather, biomass as a source of energy it is the only renewable source which presents similarities to fossil fuels (Badea, 2013; Koppejan, 2012). It has a high specific energy content, can be stored and transported at long distances, and it can be used to produce both heat and power (Badea, 2013; Koppejan, 2012). Also, biomass it is suitable to produce derived biofuels through other thermochemical processes, as pyrolysis or gasification (Badea, 2013; Crocker, 2010; Stevens, 2011; Basu, 2013).

Biomass combustion power plants are based on the same principle as fossil fuels power plants, which is Hirn or Rankine Cycle (Badea, 2013; Koppejan, 2012).

Biomass drawbacks compared to coals are: the high moisture content, low heating value, and limited quantities of the same source (Higman, 2003; Basu, 2006; Koppejan, 2012; Basu, 2013). Biomass has a moisture content up to 65%, while coals moisture content varies from 5% to 40% for lignite. Thus, in order to have a high efficiency of the installation a prior drying of biomass is needed (Basu, 2013). The feedstock flow rate imposes the power plant dimension. A small steam turbine plant has small overall efficiencies. On the other hand, coal use disadvantages are: high Sulphur content, high CO_2 emissions (Basu, 2013), higher extraction costs unlike biomass. A high Sulphur content asks for important investments in installations for flue gas desulfurization (Basu, 2013).

Biomass vs coal

Biomass was used as a fuel since men discovered the fire. Combustion power plants, whatever the fuel is coal or biomass, run on the same thermodynamic principle, Hirn or Rankine Cycle (Badea, 2013; Koppejan, 2012). The two types of power plants, fed by biomass or by coal presents particularities imposed mostly by fuel composition and properties.

Proximate analysis

Biomass has a high moisture content reaching in some cases 90%, while a low rank coal such as lignite or sub-bituminous coal can reach maximum 40% moisture content. A high rank coal such as anthracite has a moisture content below 5% (Basu, 2006; Basu, 2013). The higher the moisture content the lower the temperature inside the combustion chamber and the process efficiency; at 50-55% moisture content the flame becomes unstable (Basu, 2006; Stevens, 2011; Koppejan & Van Loo, 2012). Therefore, some types of fuels need at least a partial drying to a maximum limit of moisture content in the range of 5 to 35%, depending on the type of the reactor used (Basu, 2006). Fuel drying system is an important energy consumer and represents additional expenses. An alternative to a drying installation, for fuel which exceed 50% moisture content is cofiring with natural gas or coal for flame stabilization (Stevens, 2011). Cofiring, also involve extra costs with support fuel. Beside the combustion behaviour and the flame temperature and stability, the moisture also influence the combustion chamber volume, since the flue gas needs a longer residence time in the combustion chamber in order to ensure a complete combustion (Koppejan & Van Loo, 2012).

The ash content of biomass is particularly low, but for some cereal straw and residues it can reach up to 12%. For coals, the ash content can exceed 40%, depending on the coal rank and origins (Mishra, 2012); Rezaiyana and Cheremisinoff, 2005; Koppejan & Van Loo, 2012). Ash content of a fuel is important in choosing the combustion installation and the process temperature in order to avoid ash slagging and fouling (Basu, P., 2006; Stevens, C., 2011; Koppejan & Van Loo, 2012). A low ash content will reduce the cost with de-ashing, and also with ash transportation, storage and disposal, and the dust emission will be lower (Koppejan & Van Loo, 2012).

Biomass content of volatile matter is usually 60-86%, higher than coals, which does not exceed 20% (Jenkins and Ebeling, 1985; Channiwala and Parikh, 2002; Mishra, 2012; Koppejan & Van Loo, 2012). The volatile matter has a strong influence on thermochemical processes, in particular combustion, due to solid particle transformation during heating. The volatiles are the first to be released into gas phase starting the combustion process with a major influence on its kinetics. (Koppejan & Van Loo, 2012).

Ultimate analysis

If we compare biomass with lignite or sub-bituminous coal, which are low rank coal, we can affirm that these types of fuels have similar ultimate analyses. Compared to a high coal rank, like anthracite or semianthracite, biomass has a lower carbon and ash content, and a higher hydrogen, moisture, and oxygen content (Rezaiyan and Cheremisinoff, 2005; Basu, 2013). The lower the carbon content and the higher the oxygen content, the lower the combustion air needed (Badea, 2013), so in the case of coal the amount of air needed for a complete combustion is higher than in the case of biomass. Thus, the air preheating or/and feeding system for a coal power plant will have a higher capacity, which translates in additional expenses. Also, due to higher flue gas flow, the heat losses to the environment are higher.

Biomass may also contain Nitrogen, Sulphur or Chlorine, but usually those components concentration does not exceed 1% (Jenkins and Ebeling, 1985; Channiwala and Parikh, 2002; Koppejan & Van Loo, 2012). Coal contain certain amounts of Chlorine, but higher amounts of Nitrogen and Sulphur compared to biomass (Fauklker and de Souza-Santos, 2010; Rubin et al., 2007). Even though, the concentration of Nitrogen, Sulphur and Chlorine may not be high, these still have a contribution in air pollution, and corrosion, slagging and fouling (Stevens, 2011; Koppejan & Van Loo, 2012).

Nitrogen presence is the cause of formation of nitrogen oxides (NO_x) and nitrous oxide (N_2O) during combustion. Chlorine forms hydrochloride acid (HCl), Cl_2 and alkali chlorides during combustion. Sulphur forms sulfur dioxide (SO_2), sulfur trioxide (SO_3) and alkali sulphates during combustion. All these substances play an important role in corrosion, therefore in fuel, installation material selection and flue gas treatment units (Stevens, 2011; Koppejan & Van Loo, 2012).

Biomass usually has a low content of these three components, except for municipal solid residues which may have an important chlorine content (Stevens, 2011). Some types of coal have an important Sulphur content. Using coal in power plants requires important investments in installations of flue gas desulfurization. If limestone is used to reduce SO_2 emissions, then additional carbon dioxide moles will be released during the production of CaO from $CaCO_3$. Therefore, fossil fuels not only release a high amount of carbon dioxide through burning, but also through the caption of sulphur dioxide, while biomass is considered CO_2 neutral (Basu, 2010; Basu, 2013; Badea, 2013).

Heating value

High heating value (or gross calorific value – HHV) and low heating value (or net calorific value – LHV) are used to characterise a fuel based on the energy contained within its chemical bonds. The heating value of a fuel is correlated with its composition (Channiwala and Parikh, 2002; Crocker, 2010; Basu, 2013). The higher the carbon and hydrogen content, and the lower the oxygen, ash and moisture content, the higher the HHV and LHV will be. Due to its low carbon content and high oxygen content, LHV of biomasses is quite low (8 – 20 MJ/kg) compared with the LHV of a high rank coal which exceeds 30 MJ/kg (Jenkins and Ebeling, 1985; Basu, 2006; Channiwala and Parikh, 2002).

A lower LHV translates in practice in a higher feed flow, which increases the fuel transport and preparation costs.

Economical aspects

For this study was made a comparison between two power plants with an installed power of 20MW_{el}, using the same thermodynamic conversion cycle, but different fuels: biomass and coal.

In order to compare the two power plants, the fuel flow rate, the air flow rate, and the emissions were calculated in order to see the differences between these, and to see how these influence the specific investment and the operating costs.

The biomass used in this study is beach wood residues and the coal is lignite. The ultimate analysis of the two fuels compared, and their heating values are presented in table 1.

According to ROMSILVA and IFN, beech is the most common tree species in Romania. Beech forests represents 31% of the total afforested land (Rezultate IFN, 2017; ROMSILVA, 2017).

Table 1. *Proximate analysis and the heating value of the fuels*

	Units	Coal	Biomass
C	[%]	33.91	49.20
H	[%]	2.63	6.20
O	[%]	12.41	44.40
N	[%]	1.19	0.20
S	[%]	1.72	0.03
Cl	[%]	-	0.004
Ash	[%]	8.28	1
Moisture	[%]	39.86	9
HHV	[MJ/kg]	13.36	19.85
LHV	[MJ/kg]	11.93	18.38

Source: Authors' own research results; Van der Meijden et al., 2007.

Lignite is a relatively abundant coal in Romania, for another 15-20 years, but is a low rank coal with high moisture content and a low calorific value (Guvernul Romaniei and Programul Natiunilor Unite, 2008).

To compare the fuels, we calculated the CO_2 and SO_2 emission factors vs. primary energy. These emission factors are fuel characteristics. In figure 1 is presented the CO_2 emission factor vs. primary energy for beech wood residues and lignite.

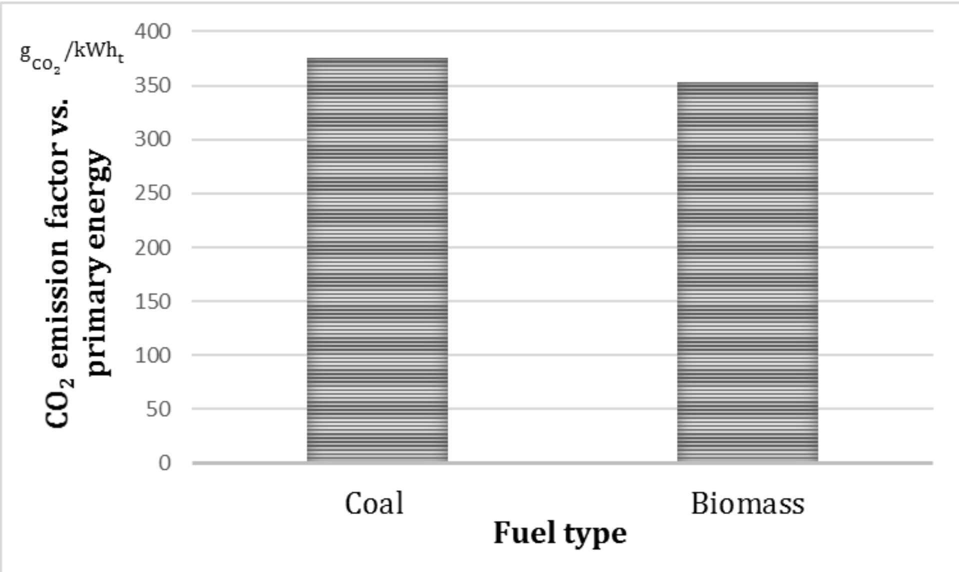

Figure 1. **CO_2 emission factor vs. primary energy for coal and biomass**

Source: Authors' own research results.

Emission factor vs. primary energy is a fuel feature used to compare fuels for combustion process in terms of emission. From figure 1 it can be observed that the CO_2 emission factor vs. primary energy for coal and biomass are roughly equal, but in the case of biomass CO_2 is considered neutral (Basu, 2010; Basu, 2013; Badea, 2013).

Figure 2 presents another important emission factor which is often computed for fuel comparison, SO_2 emission factor vs. primary energy which is presented in figure 2.

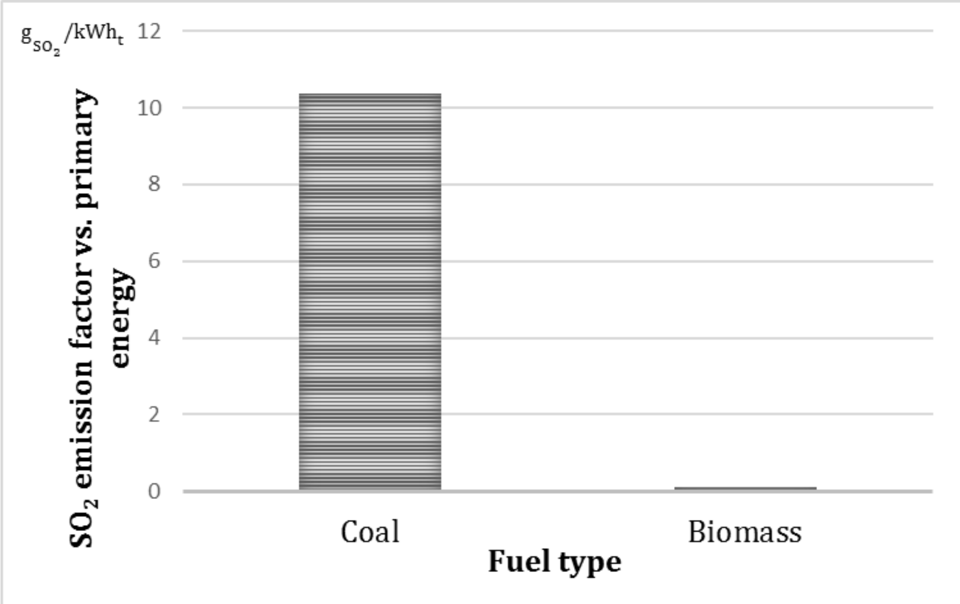

Figure 2. **SO_2 emission factor vs. primary energy for coal and biomass**

Source: Authors' own research results.

Lignite has a higher Sulphur content and a lower LHV and because of this, it has a higher SO_2 emission factor. Lignite SO_2 emission factor is 88 higher than biomass SO_2 emission factor. Sulphur emission are very important in combustion installations due to its major impact in corrosion.

To compare the power plants, the fuel and air flow rate, the emission factors and the gas flow rate were calculated. In figure 3 is presented the biomass and the coal flow rate.

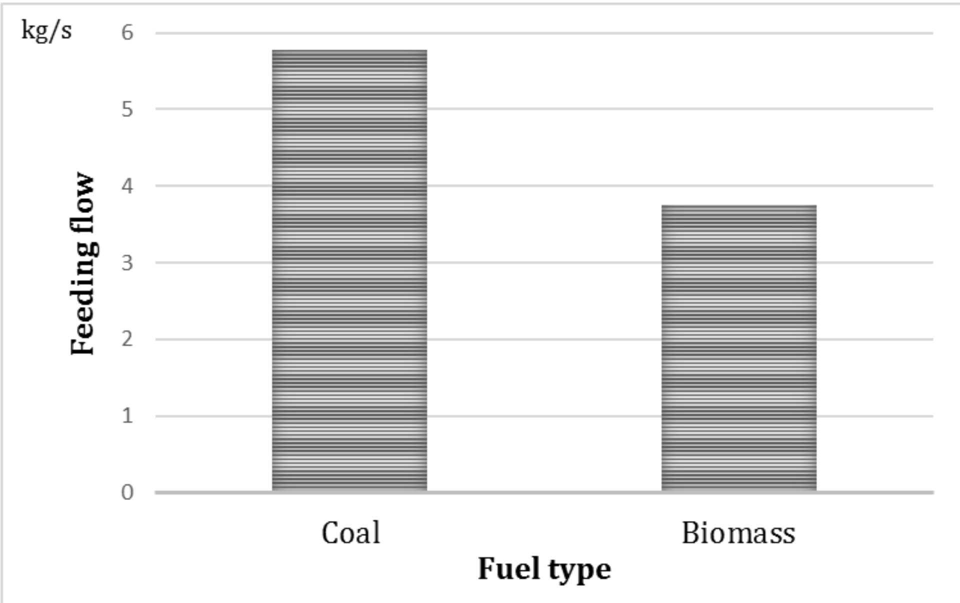

Figure 3. L**ignite vs. beech residues flow rate**

Source: Authors' own research results.

Coal flow rate is one third higher than biomass flow. Fuel costs will be higher in the case of coal due to the higher demand and the higher extraction costs. Consistent with a higher fuel flow rate for coal is a higher air flow rate (figure 4) and a higher flue gas flow (figure 5).

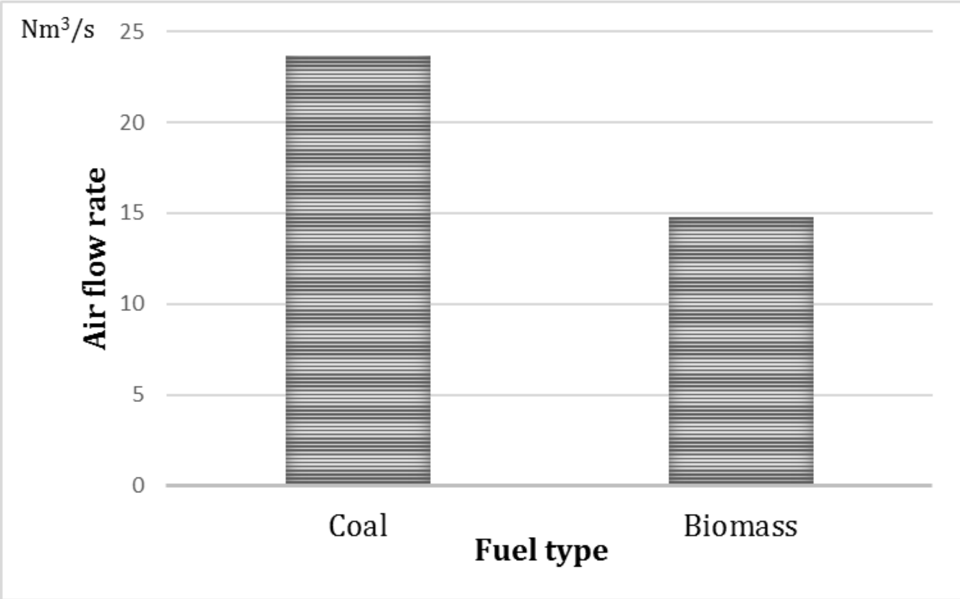

Figure 4. **Coal vs. biomass air flow rate**

Source: Authors' own research results.

In figure 4 is presented the air required for a complete combustion of the fuel. As in the case of fuel flow rate, the air flow rate is one third higher in the case of coal based power plant. Thus, the air preheating and feeding system for the coal power plant will have a higher capacity involving additional expenses compared to biomass power plant. Having a higher fuel and air flow rate, and also a higher moisture content, the coal power plant will have a higher flue gas emission towards biomass power plant, as it can be observed in figure 5.

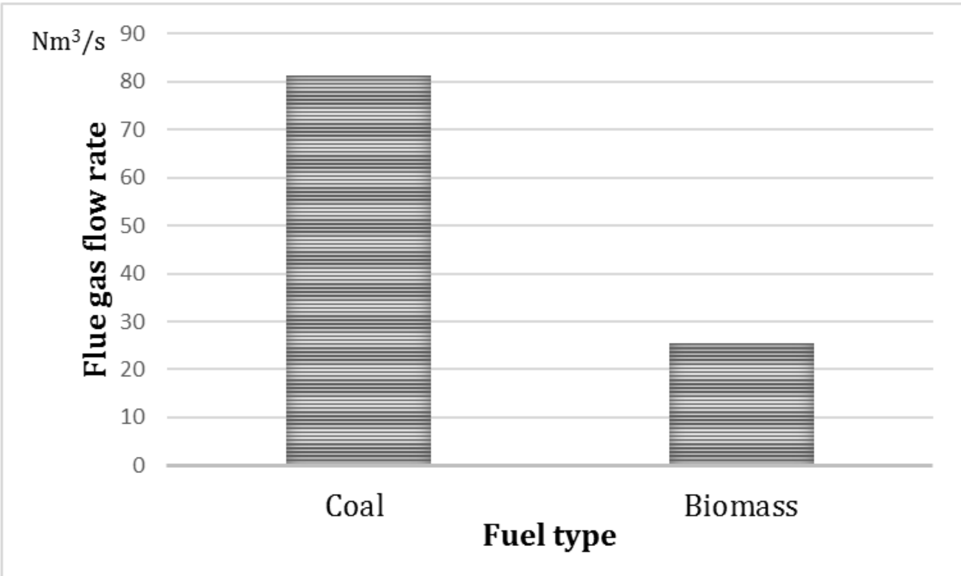

Figure 5. **Coal vs. biomass flue gas flow rate**

Source: Authors' own research results.

The flue gas emission is more than three times higher for coal combustion than is for biomass. Due to higher flue gas flow, the heat losses to the environment are higher for coal, and the flue gas cleaning system has a higher capacity and it is more expensive.

Important emission computed to compare different power plants are CO_2 and SO_2 emission factor vs. net energy (figure 6 and 7, respectively). In figure 6 is presented the CO_2 emission factor vs. net energy for coal and biomass power plants.

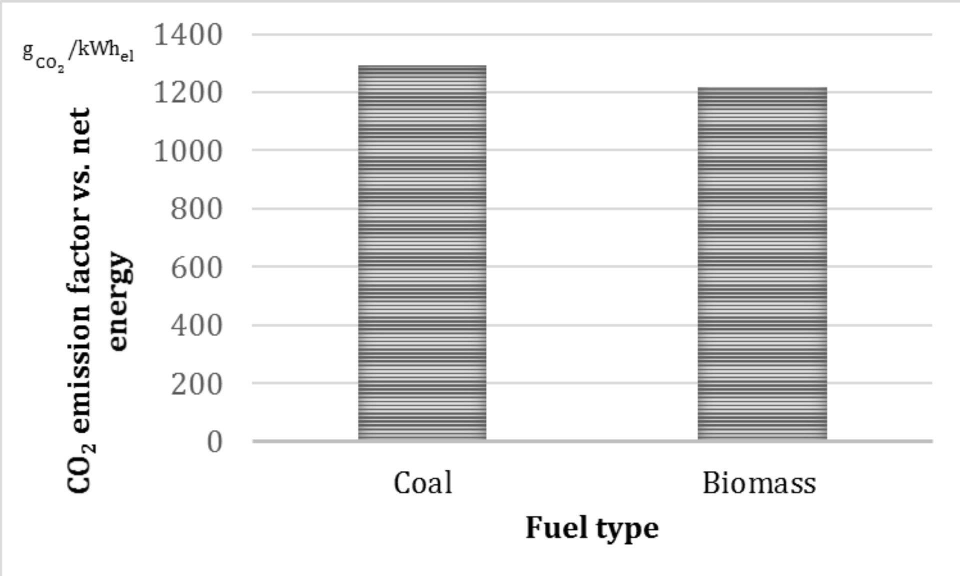

Figure 6. **CO_2 emission factor vs. net energy for coal and biomass**

Source: Authors' own research results.

The CO_2 emission factor vs. net energy is roughly equal for both fuel used. As we mentioned above the biomass is considered CO_2 neutral, consequently only the coal power plant represents a source of CO_2 pollution.

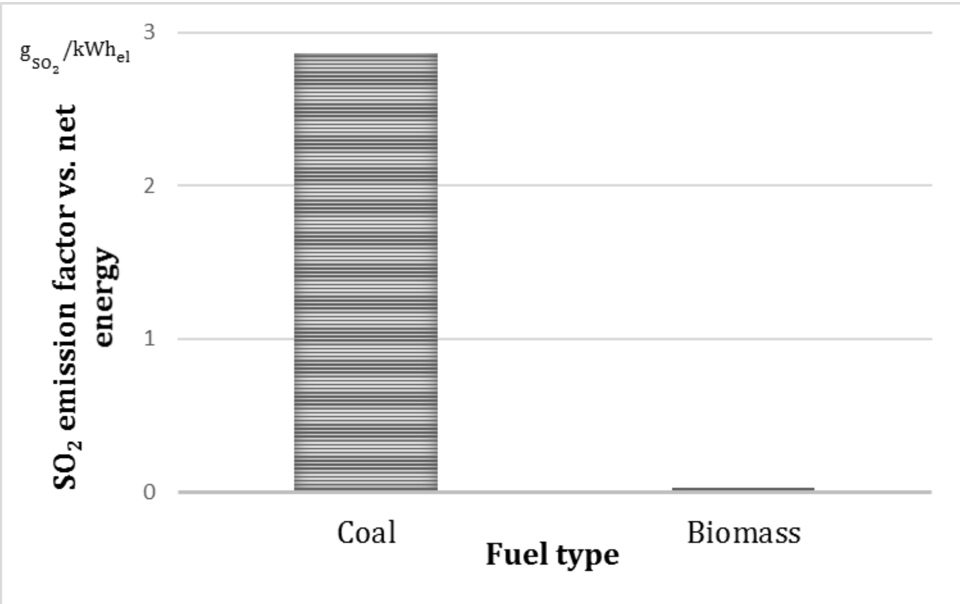

Figure 7. **SO_2 emission factor vs. net energy for coal and biomass**

Source: Authors' own research results.

As in the case of SO_2 emission factor vs. primary energy, the emission factor for coal is 88 times higher than for coal. Due to a such low emission factor of 0.03 g_{SO_2}/kWh_{el} the biomass combustion power plant doesn't need a flue gas desulphurization installation which implies additional investments. On the other hand, the coal power plant needs a flue gas desulphurization installation, which rises the

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investment with almost a third. Also, the coal power plant requires specific materials corrosion resistance.

Conclusion

Biomass was the first source of energy discovered by men and it has been intensive used until seventeenth century when coal took it place (Higman and Burgt, 2003). Coal was a good placeholder for wood due to its good quality compared to biomass, but coal is a finite resource. Furthermore, coal is a pollution source which must be replaced with more environmentally friendly fuels. Due to its similar properties to fossil fuels, biomass as a source of energy presents many advantages compared to other renewable sources.

In this paper was study the comparison of two power plants with an installed power of $20MW_{el}$, using the same thermodynamic conversion cycle, but different fuels: biomass and coal. The power plants were analysed in order to reveal the differences in specific investment and operating costs.

Computing results revealed that coal power plant requires one third more fuel and air unlike biomass power plant, and the flue gas emissions are three times higher for coal combustion. Consequently, the air preheating or/and feeding system and the flue gas cleaning system have a higher capacity and are more expensive. Also, the fuel costs will be higher for a coal power plant.

Biomass is considered CO_2 neutral, therefore only the coal power plant is considered a CO_2 pollution source.

SO_2 emission factor is 88 times higher when using coal, therefore a flue gas desulphurization installation is required for the coal power plant, which can increase the specific investment with one third compared to biomass power plant.

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