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# Environmental performance assessment of retrofitting existing coal fired power plants to co-firing with biomass: carbon footprint and emergy approach

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ABSTRACT

To reduce the emission of greenhouse gasses, developed countries tend to increase the use of environmentally friendly renewable energy sources. Retrofitting of existing coal fired condensing power plants to co-firing with biomass is a generally accepted method for decreasing the dependency on fossil fuels and carbon-dioxide emission reductions.

To determine if the co-firing is an environmentally friendly solution, two methods are used to cover all significant aspects of electricity production process that may influence the environment: carbon footprint and emergy evaluation. These environmentally accounting approaches were chosen to determine the maximum supply distance of biomass that allows the co-firing of coal and biomass to be more environmentally efficient than the pure coal combustion. Furthermore, geological origin of the coal combusted is taken into account, considering that the environmental inputs for feedstock creation varied throughout the history.

The results of the study showed that the addition of approximately 20% biomass to the mass of the combustion mixture causes the decrease in carbon-dioxide emissions for nearly 11–25% and total emergy flow for 8–15%. However, further results indicate that the co-firing process is environmentally acceptable if the biomass supply stocks are within the area determined by maximum supply distances. Nevertheless, the supply area radius resulting from the emergy evaluation is 49–62% shorter depending on the coal type combusted. Furthermore, the emergy loading ratio of co-firing was lower than for the pure coal firing (10.65 compared to 12.39, respectively) indicating that the co-firing process causes less pressure on the ecosystem.

## 1. Introduction

Global warming presents increasing and certain threat for the future with physical, social, ecological and large scale impacts. Analysis conducted by EPA (2009) predicted that without switching to renewable energy resources, carbon-dioxide concentration will reach 500 ppm by 2030. About 41% of global carbon-dioxide emissions are from electricity and heat production, with 43% emitted from coal combustion in thermal power plants (IEA, 2012). Taking into account emission factors and impact on global warming process, with rapidly decreasing reserves of fossil fuels, one of the primary goals for securing environmentally friendly future is decreasing the dependency on fossil fuels and incorporating renewable sources for energy production.

Refurbishment of the existing power plants to adapt to new emission regulations has become one of the major concerns in the electricity production sector. As suggested by Geisbricht and Dipietro (2009), current options for refurbishment are: retrofitting with carbon capture and sequestration (CCS), repowering with advanced coal combustion technologies, measures for improving the overall efficiency of the plant or switching to co-firing with (or pure firing) renewable fuels with low carbon content. Gerbelová et al. (2012) evaluated the effect of retrofitting Portuguese fossil fuel power plants with CCS, and the study showed that this technology can significantly reduce carbon-dioxide emissions, but with

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the overall efficiency decrease of average 19–33% and with additional capital costs. However, the results also suggested that CCS investment is feasible if the emission taxes are high (85–140 $/$tCO_2$). Additionally, co-firing of coal and biomass in traditional pure coal-fired boilers for electricity and heat production presents a promising cost-effective and efficient technology for increasing the participation of renewable sources in this sector. This system allows extensive combustion of biomass with higher efficiency than the one currently achieved in pure biomass combustion systems. Considering that biomass usually has higher moisture and oxygen content in its composition (and lower density than coal), for efficient and safe co-firing process to be achieved, an in-depth understanding of the process properties under a wide range of conditions is required. Many different biomass types can be used for co-combustion with coal. Wood, residues from forestry and related industry sectors, and agricultural residues are all widely available and suitable for this process. For the biomass combustion, it is considered that the total amount of carbon-dioxide emitted from its combustion is absorbed by the new plants whilst growing (Pawelzik et al., 2013), keeping the carbon cycle in balance. Considering these benefits, new EU regulations such as Large Combustion Plant Directive (European Commission, 2001) and Integrated Pollution Prevention and Control Directive (European Commission, 2008) imply increased usage of biomass.

Taking into account previously explained benefits, retrofitting existing power plants instead of closing them, and building new carbon efficient ones, is a possible and attractive solution. A techno-economical assessment of retrofitting existing coal power plant to co-firing with biomass has been conducted by De and Assadi (2008). Their conclusions were that emissions are significantly decreased, but the cost of retrofitting increases with the installed capacity of the plant. Additionally, the cost decreases for the plants with higher capacity (over 250 MW). Furthermore, for co-firing mixture with high levels of biomass, specific and initial costs are increased. Consequently, the price of produced electricity also increases. Another techno-economical analysis for coal and biomass co-firing was presented in the work of Gomes et al. (2013). The study considered the possibility of implementation of decentralized Small Thermal Power Plants (STPP) in the Brazilian state Rio Grande de Sul with the co-combustion of different biomass waste and local coal in fluidized beds. The 0.25 $MW_{th}$ pilot plant was used for combustion tests and the integrated system for energy generation, carbon crediting and sand lime bricks manufacturing was considered. The authors concluded that the proposed integrated system coupled with economical availability presents a cleaner production approach for STTPs.

However, considering just greenhouse emissions from fuel combustion is not sufficient to assess the impact of co-firing system on the environment. All amounts of energy consumed during the process and the environmental performance of the product (in this particular case, electricity and heat) during its whole life needs to be considered. Life cycle assessment (LCA) accounts for all the emissions released by all the systems involved in the life cycle of a product, and it contributes on standardization of impact assessment of a broad variety of emissions. The LCA analysis of biomass and coal co-firing in CHP plant was conducted by Zuwala (2012). The results showed that the material requirements for the construction of co-firing installation are significantly lower comparing to the whole construction and decommissioning energy consumption for the plant. Furthermore, partial substitution of coal with biomass leads to decline of the total life-cycle non-renewable energy resources depletion. This study considered several aspects that affect the environmental performance of co-firing power plant (fuel, collection and transportation, plant operation), through coefficients of cumulative energy consumption and greenhouse gasses burdening the production of electricity. Martin et al. (2006) used exergy analysis to prove technical feasibility of co-firing. Exergy analysis is suitable for tracing the energy losses through the process, so it is beneficial for process improvements and for gauging ecosystem health and stability. The results revealed that between 48.4% and 56.2% of the exergy input is lost due to the irreversibility of the process.

To determine the environmental performance of complete co-firing system, two methods are used in this study:

1) *The carbon footprint* – this approach has become widely used concept in carbon-dioxide emissions assessments. This method has been applied to determine emission factors at different levels, such as industrial parks (Dong et al., 2013), national parks (Villalba et al., 2013), cities (Lin et al., 2013) and the whole countries (Larsen and Hertwitch, 2011). It is a measure of total amount of carbon-dioxide released into the atmosphere in the given time frame that is directly or indirectly caused by an activity to provide service or a product. Consequently, aside from fuel combustion emissions of co-firing process, all the other emission sources are taken into account: fuel transportation, ash collecting and employees travel to work. . The methodology used in this paper was devolved following the five main process steps for lifecycle emissions calculations, outlined in the PAS 2050 (PPRC, 2009):
   - Process map creation (see Fig. 1)
   - Selecting boundaries and prioritization (see Fig. 1 and Section 2)
   - Data collection (see Section 3)
   - Footprint calculation (see Sections 3 and 4)
   - Uncertainty (see Section 4.1)
2) *The emergy approach – this* method accounts for, and in effect, measures quality differences between diverse types of energy. The emergy concept and the emergy accounting have been firstly introduced by H.T. Odum during the 1970s. He defined the emergy as the available energy of one kind of previously used up directly or indirectly to make a service or product (Odum, 1996). The unit of emergy is the emjoule. Using emergy concept, fuel, electricity, human labor and all other environmental resources can be expressed in the same unit. Solar emergy of a product is the emergy of the product expressed in the equivalent solar energy required to generate it (Brown and Ulgiati, 2004). The Unit Emergy Value (UEV) is calculated based on the emergy required to generate one unit of output from a process. Solar transformity of the product, one type of UEV, is equal to the ratio of the emergy that was used in a process and the exergy yielded by the process and it is expressed as solar emergy Joules per Joule. Therefore, the lower transformity is, the smaller the emergy amount is required to produce the service or a product. Once all the types of energy inputs are on the same basis, they can be compared. After calculations of the indigenous renewable, non-renewable and purchased resources emergy flows, sustainability of the system can be evaluated through several emergy-based indices and ratios (emergy yield ratio, emergy investment ratio and emergy loading ratio). This approach has been used to access environmental performance in various areas, such as geo-biosphere (Brown and Ulgiati, 2010), agricultural systems (Ghisellini et al., 2014), and diverse industry processes (Yang and Lee, 2013; Ulgiati and Brown, 2002).

The aim of this paper is to assess the environmental performance of co-firing, considering all the inputs for the plant operation (fuels, transportation, human labor, renewable environmental resources such as oxygen and water) and combustion fuel creation (for the creation of different coal types during geological periods

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