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An evaluation of the techno-economic potential of co-firing coal with woody biomass in thermal power plants in the south of Brazil

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ABSTRACT

Brazil has favorable edaphoclimatic conditions for the cultivation of biomass for energy. On the other hand, the country plans to expand its thermal power park using fossil fuels, including coal. This paper estimates the potential of co-firing biomass from energy forests in power plants based on Brazilian coal (low rank coal) from the main deposits in the south of Brazil. The technical limits of adding woody biomass to a boiler with a fluidized bed running on Brazilian coal is evaluated along with the availability of this biomass in the south of Brazil. Findings indicate that the main technical limit for boilers operating with different mixtures of biomass and coal is the alteration in the volume of exhaust gas, which varies depending on the percentages of biomass in the co-firing. The limits for biomass availability were based on environmental sustainability and the economic viability of transport. Results indicate that biomass should be available within a radius of around 120 km, which is equivalent to approximately 4,500,000 ha. Only 0.4% of this area would be required to feed a thermal plant of 600 MW_e with 30% biomass.

1. Introduction

Emerging countries such as Brazil, China and India face the challenge of expanding electricity supply to meet a demand growing at high rates over the next two decades [1].

In fact, the Brazilian economy finds itself in a cycle of expansion which results in high growth rates for electricity consumption. Sixty-eight percent (68%) of the installed capacity was based on hydroelectricity at the beginning of 2011 [2] and this source continues to be the most important source for the expansion of the Brazilian electricity sector. However, the diversification of electricity generation should be considered to guarantee supply security to the system [3].

At present only agro-industrial residues, in terms of biomass, are used in the Brazilian power sector and there is almost no production of biomass exclusively for the use in this sector, even though the country has highly favorable edaphoclimatic conditions for energy biomass cultivation. For example, the productivity of planted eucalyptus forests in Brazil is 41 $m^3\ ha^{-1}\ y^{-1}$ and for pine is 38 $m^3\ ha^{-1}\ y^{-1}$ [4]. For many other regions around the world that produce wood in large quantities the productivity rates are much lower [5], for example, reported that, in Sweden, willow is currently grown on a commercial scale at a productivity of approximately 5 $m^3\ ha^{-1}\ y^{-1}$.

The installed capacity of coal fired power plants corresponds to only 1.7% of the total installed capacity in Brazil. However, there are ambitious expansion projects for the use of coal in the power sector. This tendency is mainly due to the existence of significant reserves of coal, above all, in the south of the country.

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[6] estimates that the Brazilian proved reserves (90% probability) of coal total 4559 Mt, mainly in the states of Rio Grande do Sul, Santa Catarina and Paraná. These reserves are exclusively of low rank coal, presenting a low heating value (LHV) in a range of between 11.3 and 20.6 MJ kg^{-1}. This LHV is mainly due to the high ash content of Brazilian coal, which is in a range of 40–60% wt. Therefore, due to the low quality of the feedstock, Brazil's coal thermal power plants are all located near the mines.

However, the expansion of the system with thermal power plants based on fossil fuels is in conflict with the need to curb carbon dioxide emissions, one of the main causes of global climate change. On this point it is worth noting that Brazil has recently declared it will adopt voluntary measures to mitigate its GHG emissions [7,8].

One option to reduce emissions of coal fired power plants is the partial substitution of biomass for coal. Especially fluidized bed boilers make co-firing a promising alternative, being the typical technology option for both low rank coals as well as for biomass. Countries such as the USA, the United Kingdom, Finland, Germany and China have been making efforts to improve the burning of low quality fuels in fluidized bed boilers [9].

This work aims to analyze the technical and economic potential of co-firing coal with woody biomass in the South of Brazil. Co-combustion of low rank coal and biomass has already been widely discussed in the scientific literature. Indeed, several studies were recently published for assessing the feasibility of co-firing biomass and fossil fuels for electric power generation. Usually, these papers focused on technological issues related to the combustion [10], environmental issues related to biomass supply [11], research and development of large combustion chambers [12] and on energy security and climate change mitigation in OECD countries [13]. However, this subject has not been treated properly for countries like Brazil, where the forest productivity is very high compared to countries where co-combustion is relatively more studied.

The analysis undertaken in this paper tackles several dimensions of major importance: the availability of biomass near the Brazilian coal reserves, the technical feasibility of co-combustion of Brazilian coal and biomass in a coal fired power plant, the viability in terms of avoided CO_2 emissions and the economic viability.

Therefore, the main scientific contributions of this study are:

- The analysis focuses on co-combustion systems of biomass and low rank coal in regions where the biomass productivity is very high, which could result in additional gains;
- The study proposes and evaluates a co-firing system of coal and biomass that will result in carbon abatement without additional cost (this is a non-regrets mitigation policy, as defined by Halsnæs et al. [14]);
- The feasibility analysis is realized by examining biomass transport, bringing together two different dimensions: the economic viability and CO_2 emissions;
- The analysis simulates real cases with input data not available in the international literature;

The second and third sections of the paper describe the methods and results, respectively. The last section includes the discussion of the results and points out proposals for future research based on the present study.

2. Methods

The methodology for assessing Brazil's co-firing potential was based on four steps: the first step analyses the biomass availability in the region where most of the Brazilian coal reserves are located. The second step assesses the technical co-combustion potential, tackling the technical limits given by the combustion equipment and biomass availability. The third step evaluates the CO_2 reduction potential comparing emission reductions due to coal substitution with emissions caused by biomass supply. Finally, the last step considers the economic viability of the technology.

2.1. *Availability of biomass near the Brazilian coal reserves*

The study focuses on the biomass potential in the south of Brazil covering the states of Rio Grande do Sul, Santa Catarina and Paraná, which is where Brazilian coal reserves are concentrated, as mentioned before in this article. The potential of all bioenergy depends on the availability of adequate arable areas [15]. In this region there are large agricultural productions of sugarcane, soybean, wheat and rice and a large furniture industry. Nevertheless, the evaluation of the residual potential is a complex challenge, as much for the existing potential as for the future potential, since the supply of raw materials will be conditioned to the expansion of agricultural and forestry activities as well as industrial activities. In the same way, it is worth considering that the use of residues (agricultural and forestry) as inputs for power generation implies the removal of an important source of nutrients and organic material from the soil, which is not interesting from an economic or environmental point of view.

The cultivation of forests (energy forests or energy plantations) exclusively for power generation can create a sustainable and economically viable option, generating genetically selected uniform material of high spatial energy density [16]. As such, the evaluation of biomass potential undertaken in this study will focus on the potential of energy forests. The evaluation is realized by the review of technical reports of the relevant associations of the Brazilian forestry sector.

2.2. *Technical feasibility of co-combustion*

Basically this section aims at answering the following questions:

- What is the technology to choose for co-combustion regarding boiler type and size for low rank solid fuels?
- What is the flexibility of co-firing Brazilian coal and eucalyptus in CFB plants?
- What is the technical limit of co-firing in terms of biomass availability?