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Limits to co-combustion of coal and eucalyptus due to water availability in the state of Rio Grande do Sul, 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 Brazil's high ash coal. This study estimates the potential of co-firing biomass from energy forests in power plants fired with Brazilian coal in the state of Rio Grande do Sul, Brazil, focusing on the limits given by biomass and water availability. Results show that the state holds coal reserves that could support a potential of approximately 8 GW. Referring to limits due to water availability, different outcomes were found for the various coal fields in Rio Grande do Sul. The Candiota coal field, which represents the most important coal field, holding a capacity of 4 GW, shows severe restrictions for water availability that would be aggravated by intense eucalyptus cultivation.

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. Some 64% of the installed capacity was based on hydroelectricity at the beginning of 2011 [2] and this resource continues to be a very important source for the expansion of the Brazilian power sector. However, the diversification of electricity generation should be considered to guarantee supply security to the system, since the control of the dispatch of hydropower plants is limited by climatic conditions [3].

Many regions in Brazil offer highly favorable edaphoclimatic conditions for energy biomass cultivation. However, 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 thermal power generation. For example, the productivity of planted eucalyptus forests in Brazil is 41 m^3/ha/yr and for pine is 38 m^3 ha^{-1} yr^{-1} [4]. For many other regions around the world that produce wood in large quantities the productivity rates are much lower, such as 5 m^3/ha/yr for willow plantations in Sweden [5].

The installed capacity of coal fired power plants corresponds to only 1.7% of the total installed capacity in Brazil [2]. 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. The Brazilian proved reserves (90% probability) of coal total 4559 Mt [6], situated mainly in the states of Rio Grande do Sul, Santa Catarina and Parana. These reserves are exclusively of low rank coal, presenting a low heating value (LHV) of about 13,000 MJ/kg. The low heating value is due to the high ash content, which is in a range of 40–60 wt%. Because of the low energy content, power plants fired with Brazil's coal are all located near the mines [7].

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 declared it will adopt voluntary measures to mitigate its GHG emissions [8]. One option to reduce emissions of coal fired power plants is the partial substitution of biomass for coal. This work aims to analyze the potential of co-firing coal with woody biomass in the state of Rio Grande do Sul (RS). The analysis undertaken tackles especially the subject of biomass and water availability near the Brazilian coal reserves. Water availability restricts both operation of thermal power plants and capacity of biomass cultivation. Both activities need to occur in the proximity of the coal fields, since the viability of transportation of biomass and low rank coal is restricted.

Co-combustion of low rank coal and biomass has already been widely discussed in the scientific literature. Numerous studies were published for assessing the feasibility of co-firing biomass and fossil fuels for electric power generation. Most of the studies published in this area focus on technological issues related to

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Nomenclature

Acronyms

BNDES	National Bank for Economic and Social Development of Brazil
CFB	circulating fluidized bed
d.b.	dry base
DNPM	National Department of Mineral Production
FEPAM	state foundation for the protection of the environment Henrique Luiz Roessler
LHV	lower heating value
NO_x	nitrogen oxides
RS	state of Rio Grande do Sul
SEMA	state environmental protection agency in Rio Grande do Sul
SO_x	sulfur oxides
wt	weight

Abbreviations used in formulas

$\dot{m}$	water mass flow (kg)
C_p	specific heat of water (kJ/(kg K))
T	water temperature (K)
C	cooling water after use
WBB	properties of the water body before return of the cooling water
WBA	properties of the water body after return of the cooling water
B1	coefficient that indicates (total annual water consumption)/(average annual water availability)
B2	coefficient that indicates (total annual water consumption)/(minimum annual water availability)
B3	coefficient that indicates (water consumption during summer)/(average water availability during summer)

combustion [9,10]. Other issues analyzed in several studies consist of biomass supply chains [11,12], energy security and climate change mitigation potential [13,14]. The question of water availability for thermal power plants has also become a subject of growing interest [15–17].

However, the present study presents some new dimensions that have not been treated sufficiently yet in the scientific literature. Firstly, the subject of co-firing has not been examined properly for countries like Brazil, where the forest productivity is very high compared to countries were co-combustion is relatively more studied. Furthermore, the joint analysis of biomass and water availability represents an important and new approach for the analysis of the viability of co-firing projects. Finally it should be mentioned that the present study is based on previous research on the technical, economic and environmental viability of co-combustion of coal and eucalyptus in the state of RS [18]. In the present study, issues related to biomass availability were further detailed and the dimension of water availability was included. 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. Methodology

The methodology for assessing the limits to co-firing given by water availability was based on four steps. During the first step, the potential for the installation of coal power plants was assessed. Subsequently, the water availability in the proximity of the coal fields was analyzed, using georeferenced data supplied by the local environmental agency. By means of these data restrictions for the installation of coal power plants by water availability were determined.

In the next step, the potential for eucalyptus cultivation was investigated, considering the maximum transport distance that is economically viable. In the last step, the effects of eucalyptus plantations on the water availability in the region were studied.

2.1. Assessment of the coal power plant potential

In order to analyze the potential for power plants fired with coal from the state of Rio Grande do Sul, coal reserves whose exploration is economically feasible were quantified and localized by means of georeferenced data. Data were obtained from the National Department of Mineral Production (Departamento Nacional de Produção Mineral – DNPM) [19,20]. In the next step, the technical lifetime and the overall efficiency of a typical power plant were defined for the combustion of the local coal. Via these numbers, the installed capacity (in GW) that could be put in place if all local coal reserves were used for power generation was determined. Water use and water consumption were analyzed in detail, since these data were used subsequently to inspect the water availability for coal power plants.

All coal reserves in the RS state hold coals with extremely high ash contents. In order to use this high ash coal as Run-of-Mine fuel, the use of fluidized bed combustion technology is assumed, since circulating fluidized bed boilers (CFB) permit the processing of fuels with ash contents over 50% [21]. Moreover, CFB technology is also considered the most appropriate technology for large scale biomass combustion [22,23]. The fuel properties that were adopted for this study are listed in Table 1. As fuels, coal from the Candiota coal field and eucalyptus were chosen. The Candiota coal field holds the most extensive reserves. As biomass, eucalyptus grandis was selected, given its high productivities and good behavior during combustion [24].

In order to define plant performance, data from the scientific literature [26–32] were analyzed and adopted to the conditions of the case studied and a mathematical model was built using a spreadsheet application.

Several assumptions were made relating to technical characteristics. The power plants were expected to achieve an operating life of 45 yrs [33]. For the capacity factor the value of 60% was assumed [34]. This low capacity factor is due to the fact that Brazil's thermal power plants operate in conditions of partial flexibility, given that the dispatch of hydro power plants is the priority. Thus, thermal power plants reach their full capacity only during the dry season. For the steam cycle, an ideal supercritical cycle with steam conditions of 24.1 MPa/593 °C and reheat at 5.0 MPa were adopted. Three cooling systems were simulated: once-through cooling, wet cooling tower and dry cooling tower. A detailed description of these systems can be found in [30]. With regard to the ambient conditions, 25 °C were assumed as the average temperature and 60% as the average air humidity.

The internal energy consumption is mainly caused by fuel feeding systems, the condenser cooling system and exhaust gas purification [31]. Considering the emission of the most relevant pollutants, NO_x, SO_x and particulate matter, it was assumed that the power plants have to comply with the limits defined by the