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Research paper

Agricultural and agro-industrial residues-to-energy: Techno-economic and environmental assessment in Brazil

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A B S T R A C T

This study aims to quantify the environmentally sustainable and economically feasible potentials of agricultural and agro-industrial residues to generate electricity via direct combustion in centralised power plants in Brazil. Further, the energy savings and greenhouse gas (GHG) reduction potential of replacing natural gas-based electricity by bioenergy have been assessed. To this end, a methodology has been developed based on an integrated evaluation, incorporating statistical and geographical information system (GIS)-based analysis, and a life-cycle-assessment approach. Results reveal that the environmentally sustainable generation potential is nearly 141 TWh/year, mainly concentrated in the South, Southeast, and Midwest regions of the country. Sugarcane, soybean and maize crop residues are the major feedstocks for available bioenergy. On the other hand, the economic potential is far lower, accounting to 39 TWh/year. The total GHG mitigation is nearly 18 million tonne CO_2e and could reach 64 million tonne CO_2e yearly, if the technical potential is considered. The gap between technical and economic potentials implies that constraints to bioenergy are not related to a lack of resources, but rather associated to economic, logistical, regulatory and political barriers.

1. Introduction

The Brazilian power sector is on a knife-edge. Historically, the country has been a World leader on renewable energy, with the share of hydropower and bioelectricity making up approximately 79% of the country's power generation portfolio in 2013 [1]. However, year after year, this contribution has been decreasing. On the one hand, on the demand side, in the last decade, electricity consumption increased two-fold up to 516 TWh/year, partly due to the rising quality of life of an emerging middle-class. On the other hand, on the supply side, the expansion of hydropower plant projects has been limited due to socio-environmental restrictions [2,3]. Accordingly, the Brazilian government has announced that the expansion of large reservoir hydropower facilities will be constrained after 2025–30 [4]. Reservoir hydro systems are equipped with water storage facilities in order to control the water sent to turbines, allowing a variation in the amount of generated power. Although these systems are particularly capable to handle peak electricity loads, they raise environmental conflicts and social concerns, especially in the Amazon basin and other environmentally sensible ecosystems. Future projects might, therefore, be limited to run-of-the-river technologies, which imply reduced water flooding and limited environmental impacts. In these systems, water is streamed without a reservoir to a pipe that supplies the water turbine and then flows freely downstream. While these systems have low ecological and climate footprint, run-of-the-river technologies have limited capacity to provide firm energy to the grid as the power generation oscillates considerably and is very much vulnerable to weather conditions [5].

The capacity of water storage in the dam reservoirs has been steadily decreasing since 2008 (Fig. 1) [6]. Aggravating the situation, the country is facing a serious drought, which, as of April 2015, reduced water level in reservoirs to an average of 31% of their total storage capacity, highlighting the vulnerability of the country towards extreme weather events [7,8]. The autonomy of hydropower systems, expressed as the number of months that hydropower plants can supply the country's power demand excluding the

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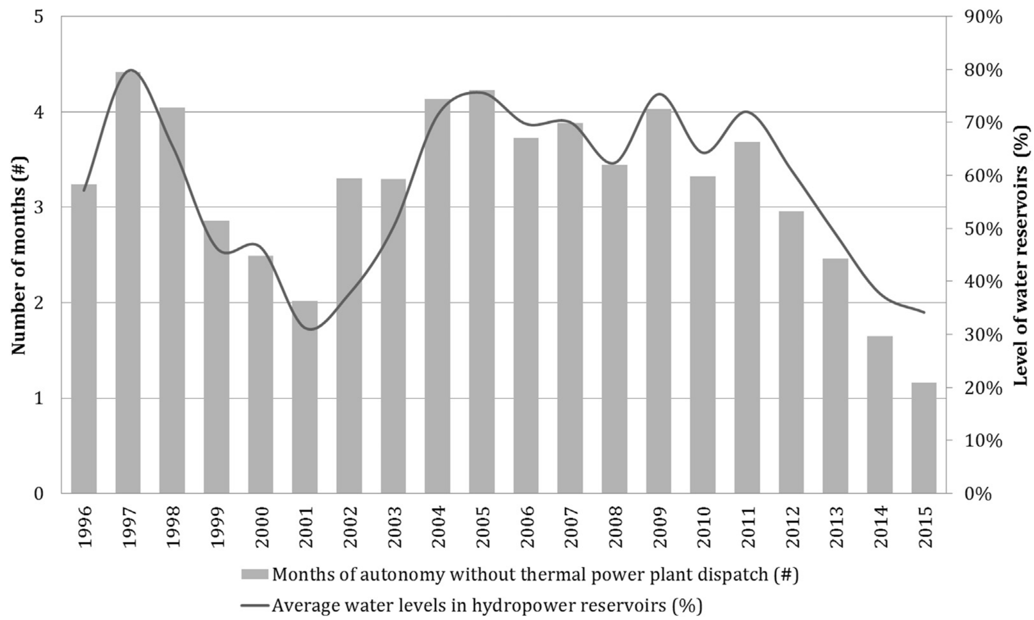

Fig. 1. Regulation capacity of hydropower reservoirs in Brazil.
Source: Own elaboration, based on [6].

dispatch of thermal power plants, has been decreasing sharply to historically low levels. While in late 1990's the water available in country's reservoirs had capacity to supply firm power equivalent to consumption needs for about four months, as of beginning of 2015 water in reservoirs only guaranteed supply up to one month of demand.

Forecasts predict that electricity consumption will double from 2010 levels to 1100 TWh in 2035 [9]. Following a business-as-usual scenario, this growth will partly be met with fossil fuel resources [10]. In recent years, the Brazilian government has announced aggressive investments to explore pre-salt oil and gas reserves and even unconventional natural gas (shale and tight). This is seen as a strategy to increase the energy security of supply, and to foster the resilience and resource diversification of the power supply sector in particular [11]. Paradoxically, in global terms, increasing the share of fossil fuels in the electricity generation portfolio results in higher GHG emissions, with the possible consequence of inducing more severe weather events, which indirectly intensifies the vulnerability of hydropower systems. Thus, the country is currently trapped in a development vicious cycle.

Recent attention has been put on bioelectricity, as a feasible alternative to turn this tendency into a virtuous cycle. It would simultaneously diversify energy sources [12], reduce fossil-fuel dependence [13,14], and tackle climate change [15,16]. Although traditional, dedicated biomass has already a significant expression in the country's power supply, particularly based on sugarcane bagasse thermal power plants [17–20], there is a vast potential from agricultural and agro-industrial residues which are currently not recovered. Instead of being left on the farmland and slowly decomposed (aerobically on the field, or anaerobically in landfills or common garbage dumps), releasing GHG emissions, this valuable feedstock could be collected and processed to generate electricity via conventional thermochemical processes. Assessing the bioenergy potential is, therefore, essential to characterise feedstocks both qualitatively and quantitatively and to prospect the potential substitution of fossil fuels and the associated reduction in GHG emissions.

A small number of studies can be found in the literature that touches this subject. At the national level, the technical potential for electricity generation from major agricultural crop residues and animal manure has been estimated [21,22]. In more detail, other assessments quantified the energy potentials of the main biomass resources in different regions of Brazil [23–26]. A common limitation of these studies is the reliance on crude assumptions and simple national statistics to quantify the potential of residue production, disregarding the economic and environmental limitations of residue collection and processing. Furthermore, previous studies are restricted to a specific area in the country or to a particular technology. Another downside is the lack of georeferenced statistical data in the bioenergy potential estimations. As highlighted by [27], data about spatial distribution of biomass are needed to optimise the efficient use of resources.

Aiming at overcoming this gap, this study attempts to estimate the technical, environmentally sustainable and economic feasible potentials of agricultural and agro-industrial residues to generate electricity via direct combustion in centralised systems in Brazil. Further, it applies an integrated geographic information system (GIS)-based analysis to map residue availability and assesses how much bioenergy can replace fossil fuel resources and contribute to a reduction in GHG emissions. To this end, a statistical analysis has been conducted, followed by a GIS mapping, which identifies optimal locations for bioenergy generation centres, under techno-economic and environmental constraints. Then, a life-cycle approach has been undertaken to quantify the non-renewable energy and GHG emission savings from replacing fossil-fuel-based electricity.

This paper is structured as follows. Section 2 presents the integrated assessment applied in the study, including key theoretical principles about analytical quantification of bioenergy with a statistical based approach and GIS mapping, as well as assumptions applied in the environmental assessment. This is followed by Section 3, which discusses key results, lessons learnt and limitation of the study. Lastly, Section 4 outlines final remarks and implications of the study to policy making.