LOW-CARBON SCENARIOS FOR THE BRAZILIAN POWER SYSTEM

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ABSTRACT

The Brazilian power generation sector faces a paradigm change driven, on one hand, by a shift from a hydropower dominated mix and, on the other, by international goals for reducing greenhouse gases emissions. The objective of this work was to evaluate five scenarios for the Brazilian power system until 2050 using a multi-criteria decision analysis tool. These scenarios include a baseline trend and low carbon policy scenarios based on carbon taxes and carbon emission limits. To support the applied methodology, a questionnaire was elaborated to integrate the perceptions of experts on the scenario evaluation process. Taking into account the results from multi-criteria analysis, scenario preference followed the order of increasing share of renewables in the power system. The preferable option for the future Brazilian power system is a scenario where wind and biomass have a major contribution. The robustness of the multi-criteria tool applied in this study was tested by a sensitivity analysis. This analysis demonstrated that, regardless the respondents' preferences and backgrounds, scenarios with higher shares of fossil fuel sources are the least preferable option, while scenarios with major contributions from wind and biomass are the preferable option to supply electricity in Brazil through 2050.

INTRODUCTION

The Brazilian electricity system heavily relies on hydropower for power generation (nearly 80% of total electricity production in average over the last ten years). Although hydropower is expected to maintain a dominant role in the future, the structure of the power system is changing constrained by technical and environmental impositions. Firstly, the remaining hydropower generation potential is projected to be fully deployed by 2030 (Nogueira et al. 2014). Secondly, severe climate conditions, such as droughts, have been jeopardizing the good performance of the power generation system in the few years (Lucena et al. 2009; Schaeffer et al. 2012; Juárez et al. 2014). Considering also that scenarios for future electricity consumption reveal an expected annual increase of 3.9% (MME/EPE 2015), it becomes clear that the Brazilian power system will have to expand and, simultaneously, diversify its technology mix.

Recent works on this topic (Nogueira et al. 2014; Lucena et al. 2015; Portugal-Pereira et al. 2016) have indicated that, in business-as-usual (BAU) scenarios, higher penetrations of coal and natural gas power plants can be expected for the Brazilian power sector in the future. However, this may also imply in a higher dependence on coal and natural gas imports into the country (Lima et al. 2015). An alternative could be a higher reliance on renewable energy sources other than hydro, since the country benefits of a high potential of diverse sources dispersed along the territory, such as biomass (Portugal-Pereira et al. 2015), wind (Pao & Fu 2013) and solar resources (Malagueta et al. 2014; Oliveira et al. 2016).

To the best of the authors knowledge, so far, in a Brazilian context, only single technologies have been evaluated through multi-criteria decision analysis (MCDA). This approach does not fully reflect the existing interactions and synergies that characterize electric power systems. As such, the objective of this work is to evaluate five scenarios each one characterized by a set of different technologies with different contributions for the Brazilian power system until 2050, using a multi-criteria decision analysis tool.

The paper is organized as follows. A brief description of the Brazilian electricity system follows this introduction. Then, the methodology used in this study is resented and, subsequently, the results and discussion are detailed. At last, the main conclusions of this work are shown.

The Brazilian electricity system

Brazil is the 7th largest world economy and the 8th largest total energy consumer in the world (IMF 2015). According to the Brazilian Energy Balance (EPE 2014), electricity generation in the country is predominantly composed by renewable energy sources (RES) distributed in 76.9% hydro, 6.8% biomass and 0.9% wind. Natural gas and oil products have a share of 7.9% and 3.3% respectively, while coal products account for 1.6% and nuclear 2.7%. Brazil has then one of the most renewable energy mixes in the world.

Despite hydropower's merit, several risks arise due to the persistent drought and erratic rainfall patterns (Juárez et al. 2014), implicating the implementation of water and electricity rationing programs in some parts of the country in the near future (ONS 2015). Thus, the expansion of hydropower systems is slower than the electricity demand predicted for the next decade and is mainly limited to run-of-river and small hydro projects.

Currently, natural gas power plants are used as backup systems, but given the current pressure on the power supply sector, the low price of coal in international markets and the development and exploitation of domestic pre-salt oil reserves, Brazil may invest in natural gas and coal-based technologies for electricity generation (Nogueira et al. 2014).

Nonetheless, domestic coal brings many limitations, since it has a high ash content resulting in a low-heating-value for this fuel. Thus, future coal-based technologies are expected to run with coal mostly imported from Colombia (Lucena et al. 2015). Carbon Capture and Storage (CCS) could be an effective alternative to contribute for the GHG emission reduction, coupling this technology with thermal power units (Lucena et al. 2015; Nogueira et al. 2014).

However, there are several options for increasing the supply of electricity in Brazil without having to turn to fossil fuels.

METHODOLOGY

The methodology used in this work follows the diagram presented in Figure 1 and is described in the sections below. It encompasses five stages: (i) scenario design, (ii) criteria definition, (iii) criteria weight attribution, (iv) determination of scenarios' relative impact, and (v) scenario ranking.

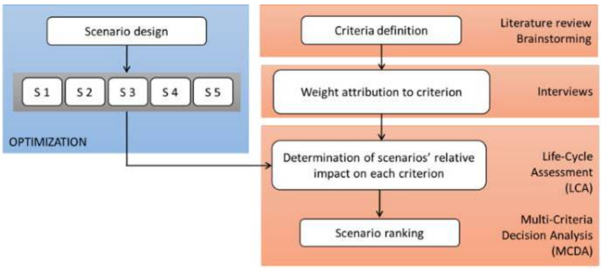

Figure 1: Methodology used in this work

The analysed scenarios were developed under the LAMP-CLIMACAP project (Lucena et al. 2015; van der Zwaan et al. 2015) and modelled using the MESSAGE-Brazil integrated model (Model for Energy Supply System Alternatives and their General Environmental impacts).

A baseline scenario and four alternatives pathways in a 2050 horizon were selected in this study in accordance to Lucena et al. (2015). Scenario 1 (S1) represents a business-as-usual scenario, gauged on baseline assumptions at regional and global levels, and was used as a reference for the other scenarios. Alternative climate policy scenarios, on the other hand, evaluate more stringent mitigation strategies and consider two different climate strategies, including carbon price mechanisms and emission cap reduction to fossil fuel related emissions. Thus, scenario 2 (S2) and scenario 3 (S3) assume carbon price paths starting, respectively, at 10USD$/t CO_{2e} and 50USD$/t CO_{2e} in 2020 and growing at 4% yearly. Scenarios 4 and 5 (S4 and S5) describe an abatement in CO_{2e} emissions reaching 20% and 50% by 2050, respectively.

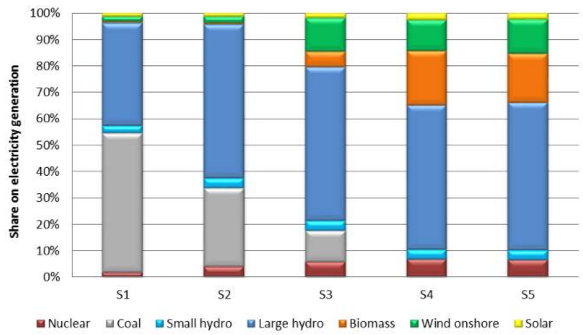

Figure 2 - Electricity generation for each scenario, by source share in Brazil 2050

Most of the criteria selected for this study follow the proposal of Ribeiro et al. (2013), but a few others were included – namely social acceptance, energy backup needs and water consumption – deemed to be relevant for the analysis of increasing share of renewable technologies. The selected criteria are also supported by the work of IAEA (2006), which provides a set of comprehensive indicators for the sustainability of the future Brazilian energy system. Overall, 15 criteria were included in the analysis: i) electricity generation system' total costs, ii) national industry development, iii) energy dependency, iv) employment creation, v) local income generation, vi) visual impact, vii) noise impact, viii) social acceptance, ix) diversity of energy mix, x) dispatchable power capacity, xi) backup needs, xii) GHG emissions, xiii) land use, xiv) public health and xv) water consumption.

To support the applied methodology, a questionnaire was elaborated in order to integrate the perceptions of experts on the scenario evaluation process. The questionnaire comprised rating type questions in numerical scale from 0 to 100, filled according to the participant perspective: 0 if the criterion is not significant to the power planning until 100, if the criterion is extremely important to it. In total, 33 questionnaires were collected in face-to-face interviews with different Brazilian stakeholders, including academia, professionals from energy companies (energy transmission and distribution), governmental planning agencies and civil society.

Whenever possible, the questionnaire was conducted by a structured interview, with a duration between 15 to 30 minutes. For the participants unable to perform an interview, the questionnaire was self-administered via e-mail correspondence. Some characteristics of the participants are illustrated in Figure 3.

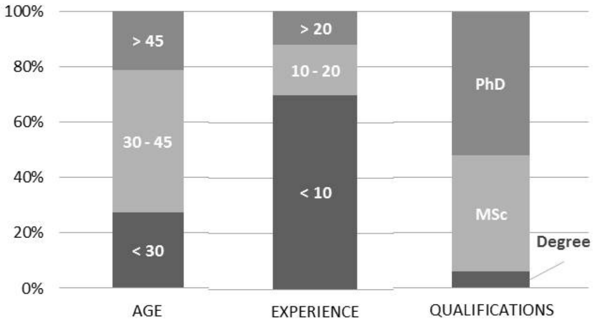

Figure 3 – Participants characterization

Scenarios were evaluated using an adapted version of the Multi-Criteria Decision Tool to Support Electricity Power Planning described in (Ribeiro et al. 2013). One important improvement to the initial MCDA methodology was the inclusion of Life-Cycle Analysis (LCA) methods to estimate the environmental impacts of the evaluated energy system scenarios.

RESULTS AND DISCUSSION

The data collected from questionnaires allowed the construction of a boxplot graph presented in Figure 4, based on the weights attributed by the 33 participants. It is observed that economic criterion "Cost" has the highest weight and a symmetric dispersion between values of 80 and 100. "Visual impact" and "Noise" are the criteria with the lowest values, with a median of 35 and 40, respectively. Visual and noise impacts, often related to wind turbines operation, may not be fully acknowledged by the participants as they may be aware of these impacts but not of its extension or annoyance for local residences, since they do not reside in areas with wind farms (Brown 2011). Also, some of the participants believe that technological development can help to mitigate the noise level of wind turbines, and as such the importance of this criterion will tend to be reduced throughout the years considered in this planning period. The criterion "GHG emissions" is assigned a high weight. CO_2 emissions concern is believed to be influenced by this topic wide dissemination in the media, leading to a higher awareness for this criterion.

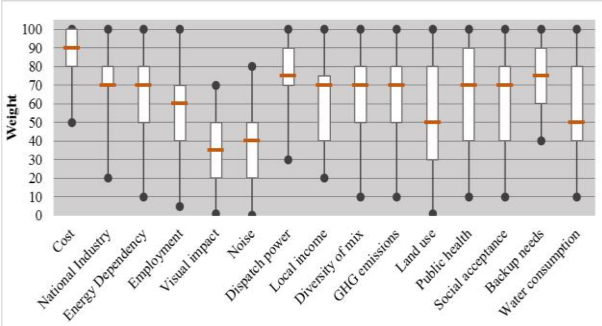

Figure 4 – Criteria weights given by interviewed participants

The high variability of the response expressed by the extension of the white box (and also extreme points) may be explained by the different backgrounds and interests of the participants. An attempt was made to investigate possible relations between the response of one participant and his/her characteristics within the group, however no significant correlations could be found between the participants' characteristics and their responses and further tests are limited by the reduced size of the sample. Nevertheless, sensitivity analyses of the assigned weights were conducted, allowing to check the extend of variation in results when parameters are varied over a realist range of interests (Qureshi et al., 1999).

The MCDA tool application allowed to rank the scenarios as illustrated in Figure 5. It can be observed that the scenario preference follows the order of increasing share of renewables in the electricity system. The best option is considered to be scenario 5, where, even with the large hydropower plants which play the major role in electricity contribution, wind power plants account significantly, since they have the biggest share when compared with the others scenarios. Scenario 5 also integrates a significate contribution of biomass power plants, considered a well-developed technology in Brazil. These results are in good agreement with the results of the case study for Mexico (Santoyo-Castelazo & Azapagic 2014). The electricity systems in Brazil and Mexico are quite different today – in the first, the highest contribution is provided by hydropower, and in the latter, the highest contribution is provided by thermal power plants. However, comparing the two works, the results of both suggest that the most sustainable option to meet the future electricity demand is a (almost) 100% renewable scenario.

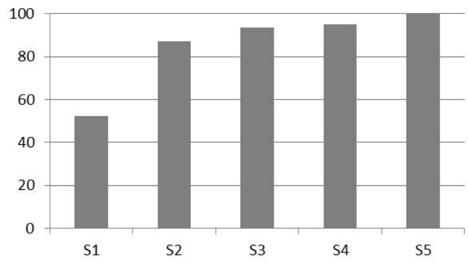

Figure 5 – Scenario ranking

The results from the sensitivity analysis are illustrated in Figure 6, presenting the scenario ranking obtained from the overall runs, by changing the weights assigned to each criteria. The emphasis of the analysis is that scenarios in the extreme positions of the ranking are always the same for all the respondents, namely S1 is always the worst option and S5 is always the best option. These results are reproduced for each MDCA run, i.e., they seem to be independent of the participants' preferences, allowing some level of confidence on the robustness of the multi-criteria tool applied to this study.

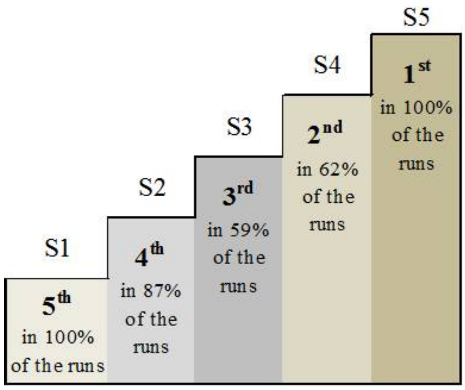

Figure 6 – Scenario ranking from sensitivity analysis

CONCLUSIONS AND FURTHER RESEARCH

The vulnerability that the Brazilian electric power system faces at the moment claims for an intervention on the integration of new competitive power generation technologies. Wind power is considered an emergent technology in Brazil, with a great unexplored potential in the country. And even, in some cases, at a higher cost when compared with fossil fuel technologies such as coal and natural gas power units, renewables can deliver a secure system, without foreign dependence and promoting a more environmental friendly way to generate electricity.

In this paper, a methodology was proposed for the evaluation of five scenarios, developed under LAMP-CLIMACAP project, drawn for the Brazilian power generation system until 2050. The scenarios consisted in a business-as-usual scenario, two scenarios with different paths of CO_2 prices and two scenarios with different goals in GHG emission reductions until 2050. In order to compare scenarios, fifteen criteria were selected regarding economic, technical, environment and social aspects affecting power generation systems. The influence of each criterion in the electricity power system was quantified in a weight, based on the perceptions of several experts. For this purpose, a questionnaire was elaborated and presented to 33 participants.

For scenarios analysis and comparison a multi-criteria tool (MCDA) was applied. This tool was developed in an earlier work for the Portuguese case (Ribeiro et al. 2013) and provides a ranking of the analysed scenarios, from "best" option to "worst" option, considering the weights attributed by the participants. It was concluded that the best option for the Brazilian electricity generation system, until 2050, is a 100% renewable scenario, with major contribution given by large hydro, wind onshore and biomass power units. It is however important to highlight that the ranking of scenarios depends on the criteria included, on the weights assigned and even on the scores assigned to more subjective criteria scored. As such, changing the underlying socio-economic moments of the country or selecting a different set of respondents is likely to influence results. Notwithstanding the proposed methodology allowed for the inclusion of different social, economic and environmental dimensions providing clear evidence that, although cost remains the fundamental criterion for most experts, other aspects, such as contribution to the domestic industry, reduction of energy dependency, local income, GHG emissions and social acceptance should not be overlooked.

Recognizing the limitations of the analysis here performed, future work is recommended to focus on the expansion of the sample of participants, in an attempt to capture wider participants' preferences and even proceed to a cluster analysis. This should allow for further explaining the responses according to the characteristics of the respondents, which is a valuable information for policy making.

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