The Brazilian Conundrum: More Hydropower, Greater Greenhouse Gas Emissions

by

Antonio Oliveira*, Tatiana Lauria, Cristiano Prado
Federation of Industries of the State of Rio de Janeiro - FIRJAN System
Av. Graça Aranha 1, Centro, Rio de Janeiro, RJ 20.030-002

*Corresponding author. Phone: 55 21 2563-4685 / E-mail: aajunior@firjan.org.br

Abstract

This paper examines the current structural change in the Brazilian electric power grid and estimates the costs arising therefrom in the form of CO$_2$ emissions. This change has its roots in the strategy adopted in recent years of directing the expansion of the power system largely to the Brazilian North; the new frontier of the hydraulic grid. Particularities of the region, however, limit considerably the size of the reservoirs, and, therefore, the amount of energy they store in the form of water. These circumstances will translate into the decoupling between the expansion of the grid’s storage capacity and the electricity demand, thus reducing the system’s security and reliability. As a result, thermopower previously used only as backup will increasingly be employed to supply base-load demand yearlong. Owing primarily to this phenomenon, the authors estimate that the Brazilian grid will become over twice as carbon intensive until 2022 as of recent years. Although this process will produce a limited impact from an international outlook regarding the CO$_2$ emissions in the period, it is the authors’ understanding that it merits further investigation as it may reach significant volumes in later decades.

1 Introduction

The early 21st century has witnessed the increasing role of sustainable development concerns in the international political agenda, as testified by important conferences such as COP and Rio+20. Prominent among these concerns are energy-related environmental issues, particularly in regard to greenhouse gas (GHG) emissions from electricity and heat generation, which account for more than 40% of the global carbon dioxide (CO$_2$) output. Answering for a significant contribution to this statistic are the major economies, which rely heavily on fossil fuels – one exception being France, due to its extensive use of nuclear energy, and, another, Brazil.
The Brazilian electric power grid is historically hallmarked by a significant presence of renewable energy sources, in particular hydropower. In effect, hydropower alone accounted for nearly 90% of the grid’s generation from 2001 to 2012, casting therefore all other sources on a complementary part. At a time when fossil fuels are responsible for over two thirds of the world electricity production, Brazil stands in the spotlight among the leading economies as the sole country where renewables cater for nearly all of the system’s output, as shown in Figure 1.

**Figure 1: Share of Renewables in Electricity Generation in the Leading Economies**

<table>
<thead>
<tr>
<th>Country</th>
<th>% of Renewables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>91%</td>
</tr>
<tr>
<td>Italy</td>
<td>29%</td>
</tr>
<tr>
<td>Germany</td>
<td>22%</td>
</tr>
<tr>
<td>India</td>
<td>17%</td>
</tr>
<tr>
<td>China</td>
<td>17%</td>
</tr>
<tr>
<td>Russia</td>
<td>16%</td>
</tr>
<tr>
<td>Japan</td>
<td>13%</td>
</tr>
<tr>
<td>United States</td>
<td>13%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>13%</td>
</tr>
<tr>
<td>France</td>
<td>14%</td>
</tr>
<tr>
<td>Average (excl. Brazil)</td>
<td>16%</td>
</tr>
</tbody>
</table>

Notes: i) Figures refer to 2011. ii) In Brazil, renewables include hydropower, wind and biomass (chiefly sugarcane bagasse).

Source: Brazil: The authors, based on data from Operador Nacional do Sistema Elétrico - ONS. Other countries: International Energy Agency - IEA website.

In respect to the future, with over 60% of Brazil’s technical and economic hydraulic potential still available, it is only consequent that the capacity currently programmed to be added to the grid will come mostly from hydropower. At a casual glance this might seem a positive prospect; a closer look, however, will reveal that the historic capital presence of hydroelectricity may in fact shrink expressively in the coming years, bringing, as a result, a larger share of other sources in the generation mix, including fossil fuels.

This grim outlook is due to the strategy adopted in recent years (roughly around the turn of this century) to direct the expansion of the electric power system largely to the Brazilian North; the new frontier of the hydraulic grid. Particularities of the region, however, impose significant challenges for the production of electricity.

As further explained in following sections, this process will represent a significant structural change in the Brazilian grid as it will become progressively vulnerable to droughts and, therefore, subject to the generation from fossil sources in order to ensure an adequate supply of electricity. In fact, the episode that broke out in 2012, when the reservoirs ebbed to historically low levels and the share of fossil fuels in the generation mix nearly triplicated, represented the first symptoms of this “silent” change, one that had been years in the coming.

The social, economic and environmental impacts arising from the growth of thermopower output from fossils in the energy mix is quite challenging a task to specify and
quantify with any approach to completeness. In this respect, this paper contributes to the discussion with an estimate of such impacts as those related to the emissions of GHG, in particular those in the form of CO$_2$, which, undoubtedly, represent an indispensable part of any comprehensive study devoted to the influences of the power grid upon the environment and the society.\footnote{According to data from the United Nations Framework Convention on Climate Change, CO$_2$ accounts for about 99% of GHG output from electricity and heat production in Annex I parties.}

It is the authors’ understanding that the magnitude of the future increase in GHG output due to the structural change in the Brazilian electricity system is presently deficient in a proper assessment; a gap that this paper aims to fill. From a similar perception, the authors address also the impact of such emissions from an international outlook, certain that the results are such as to warrant acknowledgement and consideration from the international community.

The remainder of this paper is arranged as follows. The ensuing section describes briefly the Brazilian grid, particularly in regard to its future development. The third section explains the structural change in Brazil and identifies its main implications. Section 4 provides context upon which is based the set of hypothesis that underpins the estimates presented in section 5. The last section concludes.

2 The Expansion of Brazil’s Electric Grid: More Hydropower

The development of the Brazilian power grid is closely associated with the employment of hydrographic basins for the production of electricity. The significant potential of the national basins, in addition to their distribution in the territory, permitted not only a widespread adoption of hydroelectric plants, but their construction near the main consumer markets, such as the ones in the South and Southeast (more specifically, São Paulo and Rio de Janeiro). As demand grew, however, new plants were gradually built in the other regions, the North being the most recent to harbor the expansion of hydropower.

Hydropower is nowadays expressively present throughout Brazil, being the grid’s backbone. In this context, all regions of the country are connected to each other, and integrate what is called the National Interconnected System. The importance of this arrangement lies in the fact that it allows the operation of the Brazilian grid as one single system, which is particularly important (almost imperative) in view of the different water flow regimes among the regions. In this sense, hydroelectricity which is produced in one region with abundant inflows may be transported to another that is suffering a drought\footnote{In Brazil, the drought season historically extends from May to November, the exception being the Southern region, where this season is usually experienced from December to May.}, thus avoiding the need of production from local backup thermal plants.

The installed generation capacity in the Brazilian grid in 2013 was 129,452 MW; 69% of which belonged to hydropower. Regarding the near future, the capacity currently expected to be added to the grid from 2014 to 2022 will amount to 53,601 MW, with 33,087 MW, that is, close to 60%, coming from hydropower (roughly equivalent to Argentina’s total capacity...
in 2011). This clearly indicates that the Brazilian system will remain primarily supported by hydroelectricity for many years to come.

A major share of this new hydropower, however, will be concentrated in the Northern region, following the pattern established in recent years. In fact, the three major hydro plants recently green lighted – Belo Monte (11,233 MW), Jirau (3,750 MW) and Santo Antônio (3,568 MW) – are located in the region. From the current projects expected to start operation from 2018 to 2022, for instance, no less than 87% of their installed capacity will be located in the North, which will add 17,359 MW to the grid.

The predominant presence of the hydropower expansion in the North is directly associated with the significant potential available in the region. From the 139 thousand MW currently available countrywide, nearly half is to be found in the North.

The current state of affairs in Brazil corroborates the conclusion that the expansion of the hydropower system predominantly in the North will likely continue in the coming decades. In this sense, it is important to observe that, notwithstanding its great potential, concerns regarding the impacts of hydro plants upon the biodiversity and the native population of the Amazon rainforest limit considerably the size of reservoirs and, therefore, the amount of energy they store in the form of water. Furthermore, the low relief of the North offers limited conditions for the construction of large reservoirs, particularly in regard to those that allow the regularization of output for extended periods of time, also known as storage reservoirs.

The development of the hydropower grid will thus be largely supported, as in previous years, by run-of-river plants, whose regularization capacity does not exceed the length of a few weeks. In brief, this all translates into a significant structural change in the Brazilian electric power system, one that in fact has already been in course for years, as explained in the following section.

### 3 The Decline of the Regularization Capacity of Brazil’s Electric Power Grid

As a direct result of the expansion of the Brazilian grid via mainly run-of-river schemes, there will be an increasing mismatch between the evolution of the reservoirs storage capacity and the demand for electricity, which is expected to continue in an upward trend in the ensuing years. Consequently, the regularization capacity of the power grid, defined as the length of time in which all the system’s reservoirs, if 100% full, could supply the entire demand without the need for generation from complementary sources, will suffer a continuous decline, reducing thus the system’s security and reliability.

The previous years have already witnessed a gradual decline of the regularization capacity of the Brazilian grid.\(^3\) In 2001, for instance, the regularization capacity was of 6.27 months. In 2013, however, the regularization capacity had decreased to 4.81 months; nearly a quarter less than that of 2001.

---

\(^3\) While the grid’s storage capacity expanded 22% from 2001 to 2013, electricity demand rose 59% in the intervening years.
Regardless of the gradual decline of the regularization capacity observed in previous years, the decoupling between the expansion of the grid’s storage capacity and electricity demand is expected to accelerate in the near future. Indeed, based on official government data, the authors estimate that the regularization capacity will shrink to 3.30 months in 2022; a 31% drop when compared to 2013 and a near 50% fall from 2001, as shown in Figure 2.4

**Figure 2: Evolution of the Regularization Capacity of the Brazilian Grid**

![Graph showing the evolution of regularization capacity from 2001 to 2022.](image)

*Estimate.
Source: the authors, based on data from Empresa de Pesquisa Energética - EPE (2013) and ONS.*

The regularization capacity of the power system is an important index in the planning of the grid operation. However, considering the fact that it is highly unlikely to have all the grid’s reservoirs 100% full at any given moment, it seems appropriate to gauge the regularization capacity from the actual levels verified in the reservoirs for a particular demand. To this new index the authors will refer from this point onwards as “effective regularization capacity”.

From 2002 to 2012, for instance, the system’s reservoirs were at an average of 66.6% of their capacity, being 88.8% the maximum level they ever reached in the intervening years. As displayed in Table 1, with the reservoirs at 66.6%, the effective regularization capacity declined from 4.18 months in 2001 to 3.20 months in 2013, being estimated to reach 2.20 months in 2022. A particularly telling insight this approach offers is the fact that, in 2022, even if the reservoirs were to reach the highest level verified in the previous twelve years (namely, 88.8%), the effective regularization capacity would then be merely 2.93 months, that is, lower than that of 2013 with the reservoirs at the average 66.6%.

---

4 According to EPE (2013), the grid’s storage capacity will grow 2% from 2013 to 2022 while electricity demand will increase 43% in the same period.
As stated in the Introduction, the decline of the regularization capacity of the Brazilian grid will result in a greater share of generation from other sources. Renewables such as biomass and wind, for instance, are by default considered as the first options by virtue of being comparatively less expensive than the other sources and environmentally friendly. In fact, their installed capacity is expected to grow significantly in the coming years. However, due to their low capacity factors, the contribution of wind and biomass plants to the grid can only be fairly limited, being therefore unable to face on their own the challenge of supplying the future growth of electricity demand in Brazil.

Regarding conventional base-load technologies, nuclear power provides not only flexibility but reduced carbon output. The unexpressive presence of thermonuclear plants in Brazil, in addition to the country’s substantial uranium reserves, makes this source an option for providing security and reliability to the grid. The present likelihood of a wider use of uranium for electricity purposes in Brazil in the near future is slim, however, given the lead time required for the construction of plants and the taboos that surround the issue.

Under these circumstances, the role of fossil fuels in the system is likely to grow considerably as thermopower previously used only as backup will be increasingly used to supply base-load demand yearlong. In addition, as the regularization capacity decreases, the Brazilian grid will become progressively susceptible to droughts, thus further increasing the necessity for generation from fossils. This, in fact, is precisely what has already been happening in Brazil for nearly two years as of the time of this writing, as expounded in the ensuing section.

4 The Current Scene in Brazil

In view of the significant presence of hydroelectricity throughout the history of the Brazilian power grid, thermal stations have always been cast by default in a complementary role. Many fossil fuel-fired plants, in particular, act as safeguards to make sure the system is reliable, limiting their production to the extent that the storage levels in the reservoirs offer a risk of future undersupply of hydroelectricity. As shown in Figure 3, the annual share of fossils in generation was fairly stable from 2002 to 2011, rising considerably in subsequent years.
The recent ramp-up in the share of fossil fuels stemmed from the necessity to ensure the reliability of the grid after the reservoirs went down to comparatively low levels. It started in September of 2012, when the average storage level of the reservoirs had just crossed below 57.1%, which meant then an effective regularization capacity no longer than 2.86 months. As a result, the average relative contribution of fossils in 2012 reached 10.4%; a record that would be broken in 2013.

That year, despite the wet season having provided inflows similar to those of past decades, they were not enough to recover the reservoirs back to adequate levels. Thus, many backup thermal plants triggered in 2012 continued to operate throughout 2013 to supply base-load demand. As of the first months of 2014, the severe drought that hit Brazil has put the power grid in dire situation. As exhibited in Figure 4, in March of 2014 the system’s reservoirs were down to 40.4% and the share of fossil sources in the generation mix at an all-time high of 22.1%.

Within this context, it is important to note that the current high share of fossils in electricity production has less to do with the decline of the grid’s regularization capacity but rather more with the drought that overwhelms the country. Though the system’s reservoirs should return to adequate storage levels once the drought is over, acknowledging their inherent resiliency (as shown in Annex I), it is undeniable that, as the regularization capacity decreases, the share of fossils in the generation mix will rise.

---

5 According to data from ONS, the current wet season has been the worst in the last 43 years; the inflows being 35% lower than the historical average.
Among the consequences of this structural change, the carbonization of the Brazilian electricity system will directly translate into a higher emission of pollutants. It is therefore opportune to estimate an order of magnitude of the future increase of fossil fuels in the generation mix and the consequent influence on CO\textsubscript{2} output. As presented in the next section, the results are assessed both from a national and an international perspective.

5 An Environmental Assessment of the Decline of Brazil’s Regularization Capacity: Greater Greenhouse Gas Emissions

To estimate a possible additional generation from thermopower (meaning, from plants that would operate only as backup if the Brazilian regularization capacity did not decline past 2014) to supply base-load demand from 2015 to 2022, and the consequent increase of fossils in the generation mix, it is necessary to mesh together that which is known of the present, of the past and that which is expected from the near future. An adequate arrangement of the pertinent constants and variables shall thus paint a picture of what can be understood as a likely outcome of the events currently unfolding in Brazil.

Acknowledging the average inflows of past decades, if the regularization capacity did not drop beyond 2014 the reservoirs storage levels would remain at an average of 66.6%, and the share of fossils in the generation mix at around 6.1%. Both these percentages represent the averages observed from 2002 to 2012.

In view of the decline of the regularization capacity in the coming years, this paper adopts the hypothesis that the operation of the system will aim to conserve the effective regularization capacity at an annual average no lower than 2.86 months. The observance of this principle would thus prevent an episode similar to the one occurred in 2012, which
triggered off the massive use of backup thermal plants after the effective regularization capacity crossed below that threshold. As a result, the share of fossils in the generation mix will become progressively greater than 6.1% in order to keep the average effective regularization capacity at 2.86 months as the regularization capacity decreases.

Regarding the future mix of fossils in generation, the authors assume that it will be similar to what has been observed in recent years prior to 2013, composed chiefly of natural gas and coal, these being the least expensive sources. This estimate mix, of course, evolves proportionally to the respective additions in capacity observed in 2013 and currently expected from 2014 to 2022 (as shown in Annex II).

From this picture it is possible to estimate the future effective regularization capacity of the Brazilian power grid. If the system’s reservoirs remain at an average of 66.6%, the effective regularization capacity will decline from 2.82 months in 2015 to 2.20 months in 2022, gradually increasing the gap from the 2.86 months threshold, as presented in Figure 5. In brief, this means that, if the operation of the grid is to conserve the system’s reservoirs at an average of 2.86 months, the share of thermopower production from fossil fuels in the generation mix will have to become higher than 6.1% (the average from 2002 to 2012).

Figure 5: Estimated Evolution of the Effective Regularization Capacity of the Brazilian Grid

As shown in Figure 6, the average share of fossils in generation will nearly double in eight years, growing from 6.4% to 11.7%. The additional share, that is, that which bridges the gap to 2.86 months, will increase ever the more as demand grows and the regularization capacity shrinks. Energy-wise, the output of these plants will expand over 24x, moving from 1,791 GWh in 2015 to 43,195 GWh in 2022; a total of 177,178 GWh in the intervening years.
Regarding the environment, it is appropriate to point out that, adopting the methodology used in IEA (2013), the emissions here presented relate only to CO$_2$ from fossil fuel combustion in electricity generation, not including, therefore, lifecycle emissions.

The CO$_2$ output from the additional thermopower generation will add up to 119.26 million tonnes from 2015 to 2022 in order to preserve the average effective regularization capacity at 2.86 months, as shown on Table 2. In this period, the annual output will grow over 23x, from 1.24 to 28.82 million tonnes; an increase of 27.58 million tonnes, whereas the emissions from traditional thermopower will rise by 6.66 million tonnes. It is important to note that in 2022 the output from additional generation will have exceeded the total of 2015; a considerable increase in view of the relatively short time in which it occurs.

Table 2: CO$_2$ Emissions from Thermopower Generation from Fossil Sources

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional</td>
<td>1.24</td>
<td>5.05</td>
<td>8.92</td>
<td>12.99</td>
<td>16.80</td>
<td>20.76</td>
<td>24.67</td>
<td>28.82</td>
<td>119.26</td>
</tr>
<tr>
<td>Traditional</td>
<td>25.41</td>
<td>26.52</td>
<td>27.31</td>
<td>28.19</td>
<td>29.14</td>
<td>30.11</td>
<td>30.94</td>
<td>32.07</td>
<td>229.68</td>
</tr>
<tr>
<td>Total</td>
<td>26.64</td>
<td>31.57</td>
<td>36.24</td>
<td>41.18</td>
<td>45.94</td>
<td>50.87</td>
<td>55.62</td>
<td>60.89</td>
<td>348.94</td>
</tr>
</tbody>
</table>

Source: The authors, based on data from EPE (2013), Intergovernmental Panel on Climate Change (2007) and ONS.

The CO$_2$ emissions from electricity will grow at a faster pace than generation, resulting therefore in the carbonization of the power grid. As shown in Figure 7, the average CO$_2$ output per MWh will increase considerably in the coming years, moving from 44 kg in 2015 to 78 kg in 2022.
The decline of the regularization capacity will impact meaningfully the energy-related GHG output in Brazil, causing the country to emit higher volumes. From an international outlook, Brazil may soon forfeit to France the leading position among the major economies as producer of low carbon electricity, as shown in Figure 8. It is important to note that Brazil’s position in the international rank may continue to fall in later decades as it becomes increasingly dependent on fossils whereas other countries advance their efforts towards renewables.

The carbonization of the Brazilian electricity system will impact marginally the average emissions of the leading economies. In fact, considering Brazil’s emission factor in 2022, the average rate of the leading economies would be 570 kg CO₂/MWh; 0.2% higher than the one actually verified in 2011, of 569 kg CO₂/MWh. These results merit further reflection regarding the choices that are being made in the expansion of the Brazilian electric
power grid along with the associated costs. Such considerations are presented in the ensuing section, which concludes the paper.

6 Conclusion

The Brazilian electric grid is historically based on hydropower, and will continue to be so for the foreseeable future. However, due the recent shift towards the Northern region, which imposes significant constraints on the size of reservoirs, the expansion of the system’s storage capacity has progressively lagged behind that of electricity demand. As a result, the grid’s regularization capacity is in fast decline, one that is set to accelerate in the coming years.

Under these circumstances, it will be increasingly necessary to weigh the benefits and corresponding costs of the other sources as their role becomes more and more important to the system’s security and reliability. As shown by the authors, the role of fossil fuels in the electric grid is set to grow immensely, which will lead to a yet greater increase in the output of CO$_2$. Although the estimated carbonization of the Brazilian system will cause a relatively small impact from an international perspective until 2022, it is a matter of further investigation how significant an influence it may become in a twenty, thirty or fifty years time.

The costs ensuing from the choices that have been made regarding the expansion of the Brazilian electric power system have just started to become apparent. Whether society is willing (or ready) to pay these costs is a matter that must be object of public debate, one that should acknowledge the fact that Brazil stands at a crossroads: one path leading to the inevitable carbonization of the grid; the other, to a greater use of nuclear energy and/or a more intense rate of construction of hydro plants with larger reservoirs throughout the country, including the Amazon rainforest. It is imperative, therefore, a comprehensive technical assessment of the options available and their associated costs, so that the future choices may lead Brazil to a sustainable balance between environmental protection and energy security.

The Brazilian power grid is currently undergoing a process of structural change, one that has but recently started and is due to intensify in the ensuing years. At a time when sustainable socioeconomic development occupies growing room in the political agenda worldwide, with the reduction of anthropogenic GHG emissions being one of the main targets, Brazil appears to move, perhaps unawarely, in the opposite direction. This change can very well mean the eventual end of the country’s international reputation among the leading economies for its low output of GHG as it will contribute more and more to the rise of emissions in the planet, a phenomenon presently absent from debate. Brazil is therefore one rare example of a country whose chief challenge at the wake of the 21st century is not to ascertain a strategy to transition toward a low-GHG electricity system, but to preserve it.
References


Annex I: Recent Evolution of the Brazilian Grid’s Reservoirs (Jan/2001 - Mar/2014)

Source: The authors, based on data from ONS.

Annex II: Estimated Shares in Electricity Generation from Fossil Sources

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>20.4%</td>
<td>24.3%</td>
<td>24.3%</td>
<td>24.0%</td>
<td>23.4%</td>
<td>23.1%</td>
<td>22.7%</td>
<td>22.2%</td>
<td>22.2%</td>
</tr>
<tr>
<td>Diesel Oil</td>
<td>4.2%</td>
<td>3.0%</td>
<td>3.0%</td>
<td>2.2%</td>
<td>2.2%</td>
<td>2.1%</td>
<td>2.1%</td>
<td>2.0%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>6.1%</td>
<td>5.3%</td>
<td>5.3%</td>
<td>5.3%</td>
<td>5.1%</td>
<td>5.1%</td>
<td>5.0%</td>
<td>4.9%</td>
<td>4.9%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>69.4%</td>
<td>67.3%</td>
<td>67.3%</td>
<td>68.5%</td>
<td>69.3%</td>
<td>69.6%</td>
<td>70.3%</td>
<td>70.9%</td>
<td>70.9%</td>
</tr>
</tbody>
</table>

Sources: The authors, based on EPE (2013) and ONS.