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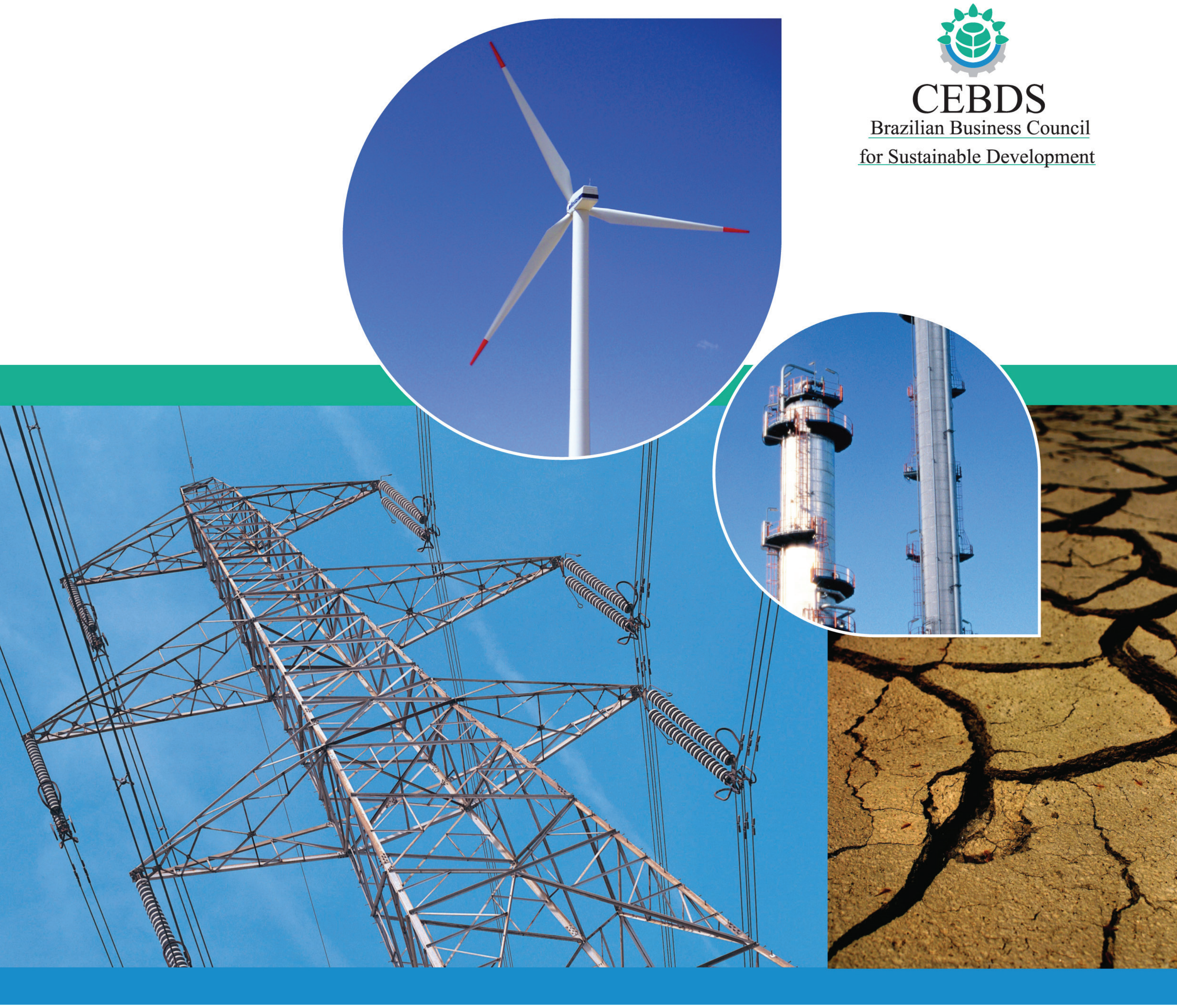

Study on adaptation and vulnerability to climate variability: cases of Brazilian electric sector

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Realization

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Execution

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The original version of thi document was launched on April 10th 2013 in an event with Brazil Ministry of Environment Director of Adaptation Policy, Karen Cope; IEA/USP researcher, Luiz Gylvan Meira Filho; and COPPE/UFRJ Energy Planning Program profesor and researcher, Roberto Schaeffer. Their observations and considerations were considered for this second edition.

Message from the President

The *Study on adaptation and vulnerability to climate variability: cases of Brazilian electric sector* is the result of a major joint effort undertaken by CEBDS and experts of its associated companies in the Thematic Chamber on Energy and Climate, with the support of WayCarbon and Conservation International. It represents a contribution to an issue whose consequences are still shrouded in uncertainties.

CEBDS sought to increase knowledge of this issue, one that will certainly have repercussions for the Brazilian economy because of the sensitivity of hydropower to climate change (temperature and precipitation) and its significant share in domestic electricity supply. Although it focuses on long-term analysis, recent events, such as the current scenario of early 2013 when the reservoirs recorded volumes well below historical levels, corroborate the main results of the study.

The preparation of this relevant study ran into difficulties such as data availability and the exceptionality of the domestic electricity system and market.

To overcome these limitations, we chose a methodology used in climate risk analysis, in which climate variability was assessed through case studies of three hydropower plants.

Despite the difficulties and limitations of the study, results point to the importance of incorporating climate issues into the strategic agenda of the electricity sector and to the urgent need to understand the degree of sensitivity of the sector as well as the associated risks and opportunities.

This effort is a corporate sector initiative to expand knowledge of these issues, emphasizing the urgent need for more detailed analyses and greater understanding of the vulnerabilities of the domestic power industry to climate variability.

Results show the impact of climate variability on the domestic energy scenario in the mid-term. The current Brazilian electricity generating strategy, which is dissociated from a more precise perception of climate changes, will lead to an environment of increased energy, economic and physical insecurity.

We hope that this contribution will not only be of assistance to Brazilian energy development but will also, and most importantly, provide a basis for further, more detailed studies on the vulnerabilities to and adaptation strategies for climate change in the corporate sector as well as throughout Brazil.

Marina Grossi
CEBDS Executive President

David Canassa
President of the Thematic Chamber on Energy and Climate Change

Contents

List of figures

List of Tables

List of Frames

Executive Summary

The Brazilian electricity sector is sensitive to exposure to extreme climate variations due mainly to the large share of hydropowers in the domestic electricity supply mix and the fact that hydropower plants are sensitive to hydrological variations resulting from climatic variability (temperature and precipitation).

This climate vulnerability is analyzed using global models, such as those of the Intergovernmental Panel on Climate Change (IPCC) with various long-term projections and scenarios. The lack of regional models, particularly for the specific case of Brazil, was one of the obstacles to carrying out this study, since the use of global models, such as the IPCC ones, would lead to uncertainties that could raise doubts about the conclusions of the study.

To meet the objectives of the corporate sector, particularly those of CEBDS, the methodology had to be adjusted to satisfy the time frames prevalent in corporate planning. A methodology for analyzing climate risks was used that captures the exposure of hydropower plants to global climate change and/or to natural climate variations for the years 2020 and 2050.

Climate variability, specifically river flows, was assessed in three case studies of hydropower plants with the following characteristics:

- A run-of-river plant with about 30MW of installed capacity (Plant A)
- Plant with a reservoir and around 100MW of installed capacity (Plant B)
- Plant with a reservoir and an installed capacity greater than 1,000MW (Plant C)

For the year 2020, the impact and exposure of each plant were analyzed, as were its sensitivities and production variations. For the year 2050, the analysis of these production variations was carried out for three scenarios: a zero change scenario, which used historical average values; a moderate change scenario and an extreme change scenario.

Results pointed to the need to problematize the conditions of the expansion of dependence of low-storage plants and/or those fully dependent on flow energy. We concluded that the vulnerability of the hydropower plants will vary according to their characteristics and their installed capacity, with respect to exposure to the flow variations of the rivers in which they are located. As a rule, plants that have reservoirs tend to have greater capacity for managing their vulnerabilities when these are scaled appropriately to their production conditions.

However, although the domestic power industry, highly dependent on hydropower, is vulnerable to climate variations, the characteristics of the National Interconnected System are such that the hydrological regimes of the various regions of the country tend to complement each other, which could result in lesser exposure of the system to climate issues.

Evaluation of actions for adaptation and vulnerability reduction in the electricity sector in the three case studies had the following results:

Power station	2050	Actions to reduce vulnerability
A **~ 30 MW**	• Surplus generation identified during the months of December, January, February and March in both moderate and extreme scenarios. • Shortage from April to November.	• Need to compensate for the months with shortages using other energy sources; • Fossil sources are less vulnerable to natural climate variability conditions (although their greenhouse gas emissions are higher); • Emissions of 30 thousand tCO2e using coal in the extreme scenario or 15 thousand tCO2e in the moderate scenario..
B **~ 100 MW**	• Generating deficit in only two months, but generation still quite higher than the assured power (about 20% higher).	• The existence of a reservoir with large storage capacity leads to less vulnerability and lower demand for deficit coverage in Plant B; • GHG emissions from the substitution of coal-based thermal energy would be more than 15 thousand tCO2e in the extreme scenario.
C **Above 1000 MW**	• Generating deficits are seen in the extreme scenario from May to November and in the moderate scenario from May to October..	• Emission of some 3 million tCO2e to cover the deficit when the water flow is lowest in the extreme scenario and about 2 million tCO2e in the moderate scenario using coal.

Based on these results, guidelines and recommendations were drawn up for adaptation and vulnerability reduction actions, including:

- Reduce the direct dependence of hydropower generation on flows and ensure additional energy supply from other sources or additional power plants;
- Expand the reliability of sector supply;
- Promote greater energy efficiency in transmission and distribution;
- Encourage the rational use of energy;
- Encourage new business models;
- Foster promotion of knowledge centered on vulnerability reduction in the electricity sector;
- Reduce conflicts with other water and area users.

The cost analysis for the adaptation strategy was based on the recommendation of ensuring additional energy supply from other sources. The annual energy deficit was calculated for each plant and the generating cost for each selected additional source was determined. To calculate the annual deficit only the amount below the assured power was taken into account. The cost of electricity for each source was based on the production cost published by EPE in 2008.

The aim of the trade-off analysis was to analyze the cost of each energy source by comparing its generation cost to the cost associated to the carbon intensity of each source, internalizing the contribution of these emissions to global climate change. The results were used in the trade-off analysis of the adaptation strategy, which identified, for each plant, the generating costs with respect to the costs associated to GHG emissions for each alternative generating source.

The importance of diversifying energy sources to ensure additional generation for hydropowers was made very clear by this analysis. Fossil sources proved to be the most resilient to natural variability and climate change impacts, although these sources emit more GHGs, which could be an obstacle to their use.

In the case of renewable sources not associated to hydrological cycles, future market trends for these sources were examined and they projected cost reductions due to government incentives, economies of scale in production and technological improvements. In this regard, there are investment opportunities associated to renewable sources, strengthened by a favorable regulatory environment, in addition to public guidelines for encouraging sustainable development, particularly those associated to the challenges of mitigating GHG emissions in Brazil and in the world. These sources have a better sustainability response, if their economic competitiveness is consolidated, as is the case of wind energy.

With regard to wind energy, given the difficulty in obtaining public data on its production costs, the study used EPE data published in 2008 and the trade-off analyses, therefore, were based on this information. Nevertheless, wind energy is already competitive in auctions, with prices falling below 100 R$/MWh.

This study clearly shows that companies are exposed to the climate variable. In this particular case, the energy generation sector was studied and it was seen to be sensitive to climate variations, both natural variations and variations associated to global climate change. Even though the study was limited to the analysis of just a few cases, preventing a confident extrapolation to the entire Brazilian grid - which could only happen after more in-depth analyses and more case studies - it clearly demonstrates that climate concerns should be part of the corporate planning agenda and strategy. If the business is affected by natural climate variations, then we can state that it is also susceptible to climate change and both the degree of existing sensitivity and the associated risks and opportunities must be urgently determined.

Introduction

The electrical power industry has generation facilities that are quite sensitive to extreme climate variations. Specifically, analysis of the vulnerabilities of the industry tends to be significant in respect of the hydrological changes caused by the Earth's mean surface temperature increase and natural variability in Brazil. Therefore, adopting scenarios with different characteristics introduces varying degrees of uncertainty for assessing vulnerability and climate change impacts in any economic activity. Special attention has been paid to these uncertainties in this paper, which uses smaller time frames, when compared to most climate change studies.

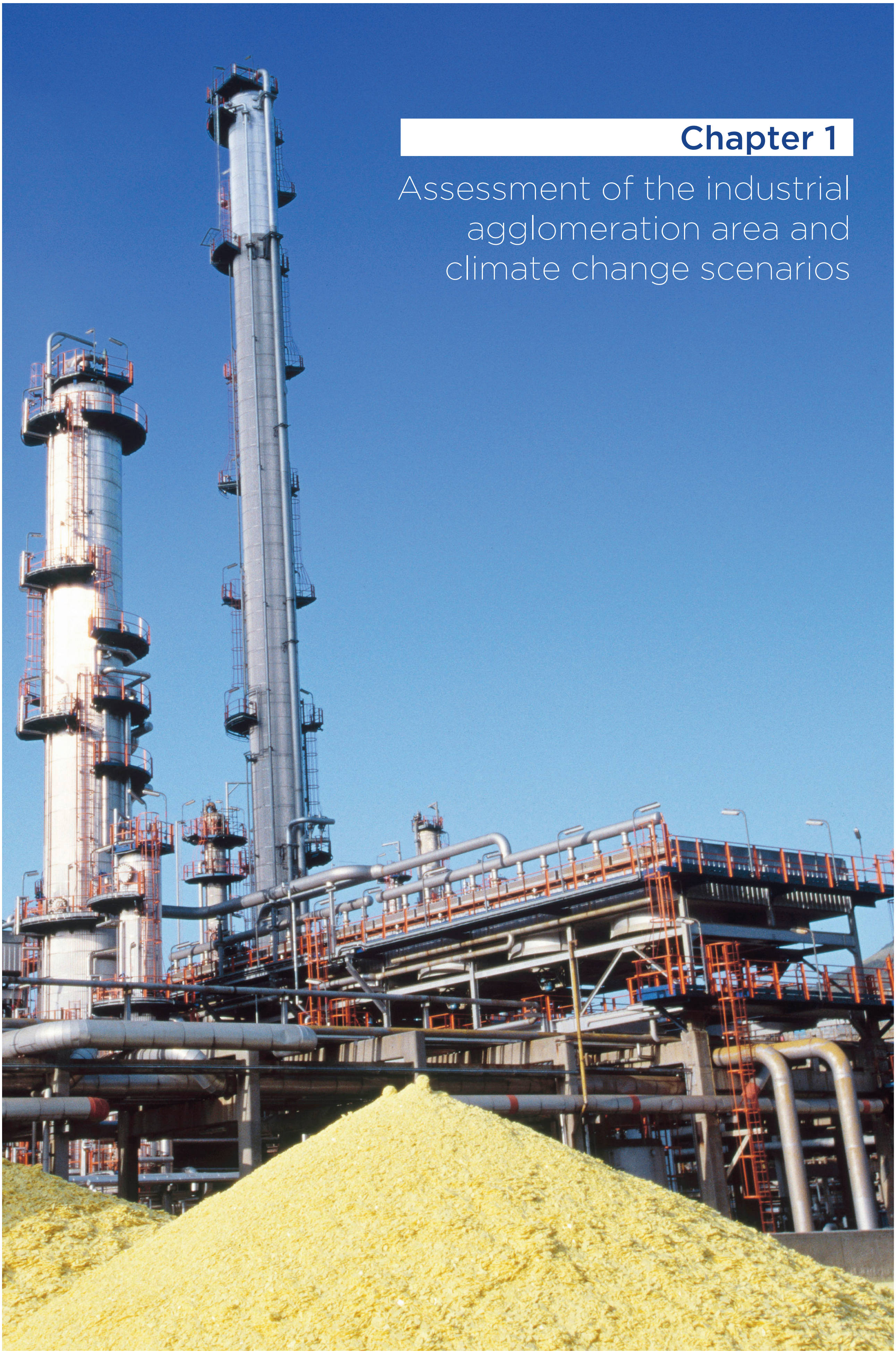
These studies generally adopt a time profile comparing the conditions of the 1961 to 1990 period to the expected results for the end of the century (2071 to 2099). However, to meet the objectives of the corporate sector, this study focused on using time frames suitable for corporate planning. Thus, the years 2020 and 2050 were chosen as the cut-offs for the analyses.

To minimize the impacts related to the major uncertainties inherent to this project and to manage them given the number of possible scenarios and variables, the study was divided into several stages, inspired by the methodology used in climate risk management. Vulnerability analyses of the adverse impacts of climate change and of the natural climate variability were carried out. These were divided into sections that deal with the conceptual framework for adaptation and risk management studies; characteristics of the electrical power industry, particularly the dynamics of the electricity generation segment, with special emphasis on hydropower sources; and three case studies of hydropower plants in Brazil. In this last stage, system variation patterns were assessed, such as maximum and minimum flows, flow frequency and trends; risk identification and sensitivity assessment related to the nature of the dependence of usable flows and installed capacity of power stations; cost analysis related to impacts, as well as assessment of the trade-off with respect to greenhouse gas (GHG) emissions. In addition to assessments and analyses, the study includes the main guidelines for action for vulnerability reduction and adaptation in the Brazilian electrical power industry.

We understand that the results of this analysis contribute to the debate on processes for identifying vulnerabilities of the Brazilian corporate sector with regard to climate change and natural climate variability. Through this study, the Brazilian Business Council for Sustainable Development (CEBDS) contributes to the knowledge pool, from a corporate perspective, of an issue whose consequences are still surrounded by uncertainties.

Chapter 1

Assessment of the industrial agglomeration area and climate change scenarios



The first activity was to identify the target geographical area in which to analyze risk exposure and vulnerability to climate change. At the same time, the IPCC climate change scenarios were studied to adapt them to the Brazilian electrical power industry, the focus of this paper. The paper includes the main guidelines for actions for vulnerability reduction and adaptation in the Brazilian electricity sector.

The results of this first stage were presented to CEBDS in the report entitled "CEBDS Study of Vulnerability and Adaptation focused on the Availability of Water Resources for the Brazilian Electrical Power Industry". It identified the basins in the area of industrial agglomerations: Paraná, Paraguay, São Francisco, Southeast Atlantic, Eastern Atlantic, South Atlantic and Uruguay. Of these, only the Paraná, Southeast Atlantic and South Atlantic basins are completely, or mostly, in the studied area. In this regard, as we shall see below, this definition of the basins and the industrial agglomeration area was useful to situate the target activities of this paper's case study.[1]

Climate change projections and scenarios were then analyzed, evaluating the changes in temperature and rainfall, with special reference to the basins that are part of the industrial agglomeration area. The reason for this analysis was to provide data for the next step: analyses of the vulnerability to the impacts of climate change.

As will be shown later, the uncertainties associated to these scenarios when brought into the paper's timeline made it difficult to apply them to the case studies. Therefore, workarounds were adopted aiming to minimize, as far as possible, the uncertainties of the obtained outcomes.

> The paper includes the main guidelines for actions for vulnerability reduction and adaptation in the Brazilian electricity sector.

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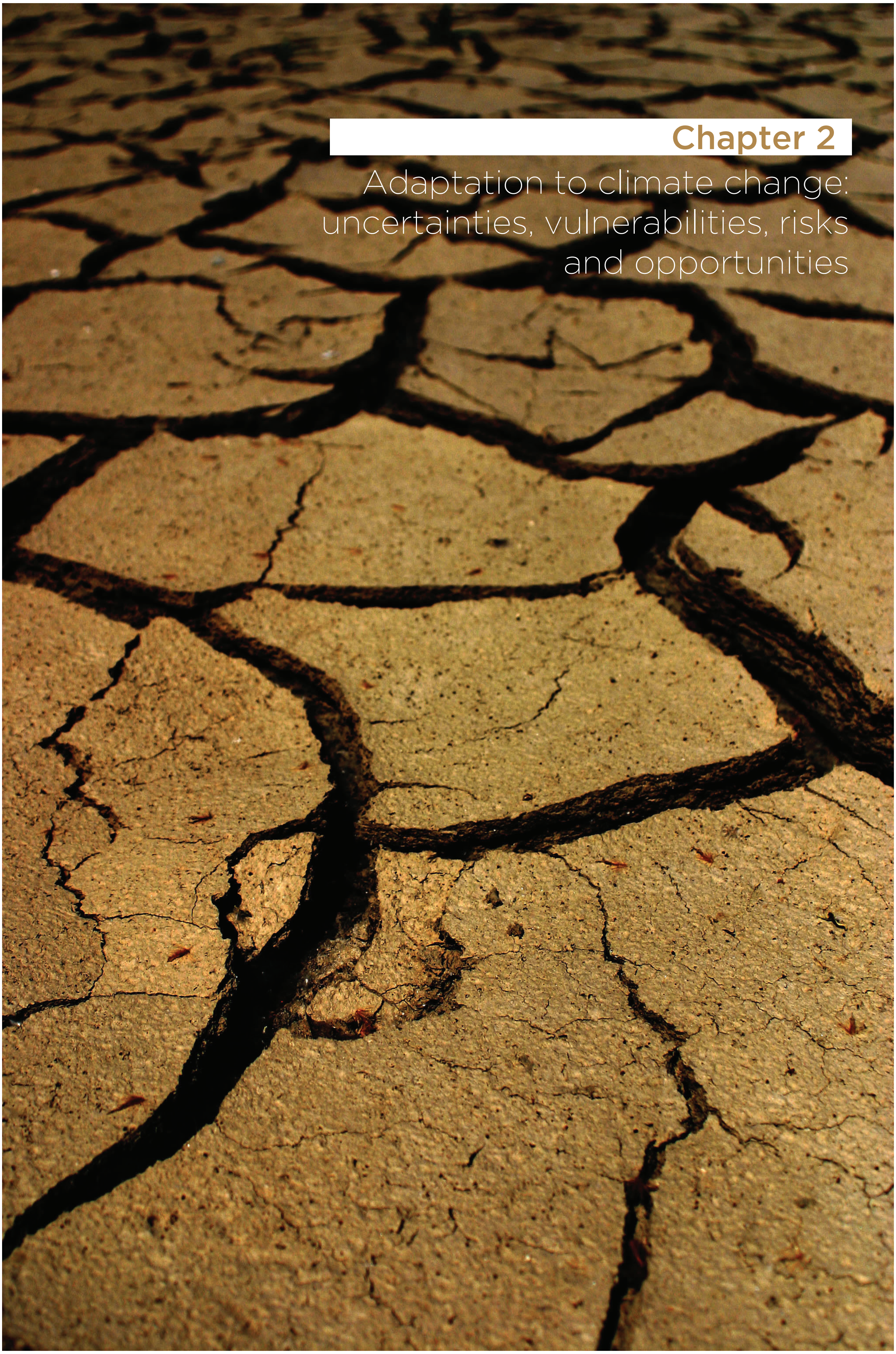
[1] Details on the background and characteristics of the industrial area are found in Annex 1.

Chapter 2

Adaptation to climate change: uncertainties, vulnerabilities, risks and opportunities



Climate variations influence living conditions, systems and socioeconomic sectors such as agriculture, hydropower generation, among others.

> *"Climate change scenario projections for the 21st Century were derived from the various global climate models used by the IPCC. The fact that global climate models use different physical representations of processes, in a relatively low resolution grid, introduces a certain amount of uncertainty in these future climate change scenarios. This uncertainty is extremely significant when assessing the vulnerability to and the impacts of climate change, as well as when implementing adaptation measures" (Brasil, 2010, p. 414).*

The climate models and projections compiled by most studies on adaptation to climate change in Brazil focus on outcomes for the end of the century (2071-2099). The levels of uncertainty also tend to be quite high when compared to the results of other global models. Convergence is only seen in the increase of global temperature. The figure below shows the anomalies projected for temperature increase at the end of the century in South America.

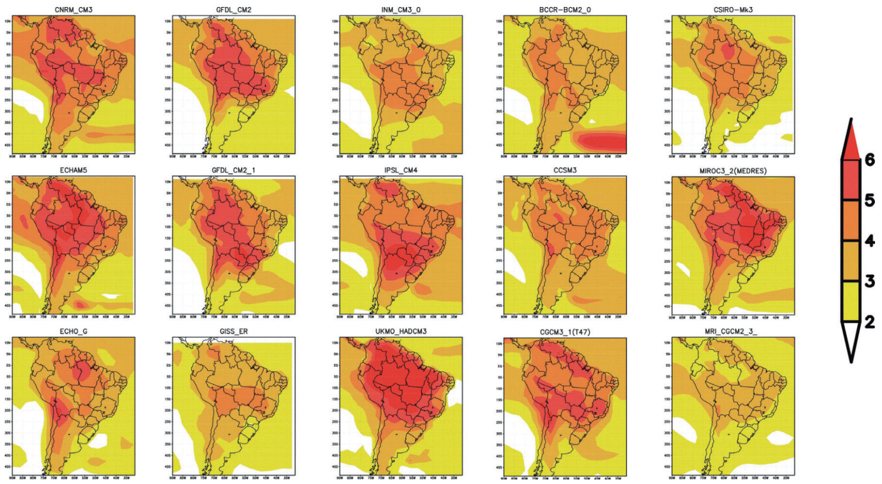


Figure 1 - Projections of temperature anomalies (°C) for South America for the period 2071-2099 (Scenario A2) with respect to the baseline period of 1961-1990 for 15 different global climate models recognized by the IPCC.

Source: NOBRE *et al*,. 2008 apud BRASIL, 2010.

As seen in Figure 1, despite differences in the amount of temperature variation, the 15 models determine that there will be an increase of at least 2°C throughout South America. However, a similar convergence is not seen in the results on the variation of hydrological patterns.

Figure 2 shows that the results of the mean daily rainfall anomalies vary by more than 100 % for the same region when the different IPCC-recognized global models are compared. Some models state, for example, that the Brazilian Northeast region will have a decrease in rainfall of up to 3 mm/day, while other models indicate an increase in rainfall of up to 3 mm/day for the 2071-2099 period.

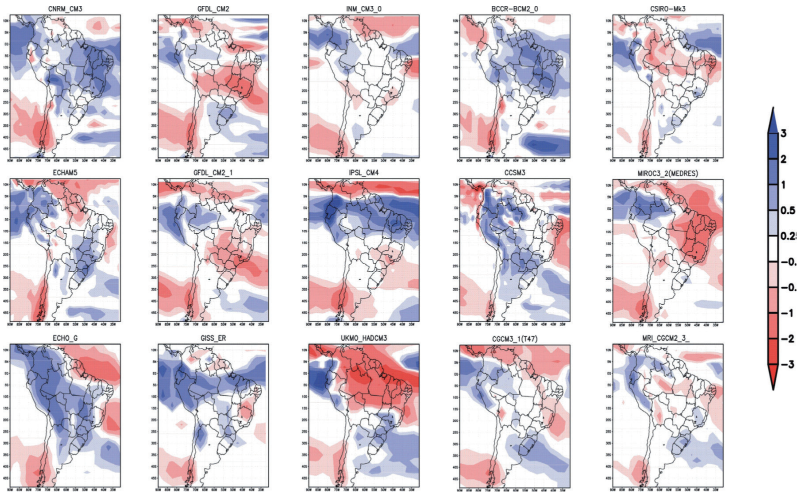


Figure 2 - Rainfall anomalies projections (mm/day) for South America for the period 2071- 2099 (Scenario A2) with respect to the baseline period of 1961-1990 for 15 different global climate models recognized by the IPCC.

Source: NOBRE et al., 2008 apud BRASIL, 2010.

Currently, the time scales adopted by the climate change models and the time frames available for decision making by the corporate world are quite different. Thus, managers and planners in the corporate universe - who must present their company's results every fiscal year - will face great difficulties in internalizing climate change projections for the end of the century (with a high degree of uncertainty) as the basis for their corporate operational planning. It is in this context that the method for climate risk management is applied, a methodology that builds its impact analysis on the conditions of historical and current climatic variability.

On identifying the vulnerabilities of a certain activity, operation or undertaking to historical and current climate variations, it is possible to make decisions and develop strategies that take into account the natural climate variability within a time frame that is compatible with business models, and thus contribute to the processes of adapting companies to future climate changes. The method is used in risk management systems to address current climate variability and, at the same time, to ensure a margin of action that will allow for climate change adaptation to be developed. The analysis used by climate risk management methodology is the bridging of climate change adaptation processes and disaster risk reduction approaches.

As seen in Figure 3, while climate change adaptation deals with long-term adjustments, the disaster risk reduction approach is centered on the analysis of geophysical hazards.

ADAPTATION TO CLIMATE CHANGE is an adjustment of a natural or human system in response to real or expected climate stimuli, or to its effects, to reduce damages, prevent losses or to explore beneficial opportunities arising from these changes.

DISASTER RISK REDUCTION is the broad development and implementation of policies, strategies and practices to minimize vulnerabilities of and disaster risks throughout society, by prevention, mitigation and preparedness.

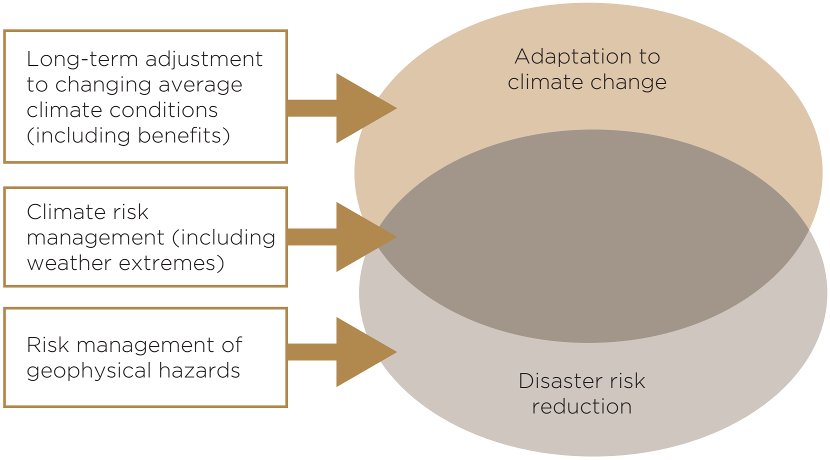


Figure 3 - Profile of climate risk management analysis.
Source: MITCHELL, 2008.

Thus, the method of climate risk analysis encompasses two essential elements in formulating risk: the probability of occurrence of a particular threat (hazard) and the degree of susceptibility of the source to the exposed element (vulnerability). IPCC (2007) defines risk as a function of the probability and the consequences of an event, where these two factors can be combined in a variety of ways. Therefore, we understand that more than one event can occur; consequences can vary positively or negatively and risk can be measured qualitatively or quantitatively.

However, the conditions for addressing risks are in an area where the climate dimension (a set associated to natural variability and anthropogenic climate change) intersects with the development dimension comprising the conditions for risk management and the actions for climate change adaptation. Figure 4 shows this relationship in a diagram.

RISK MANAGEMENT is defined as the culture, process or structure directed to maximizing potential opportunities while managing adverse effects.

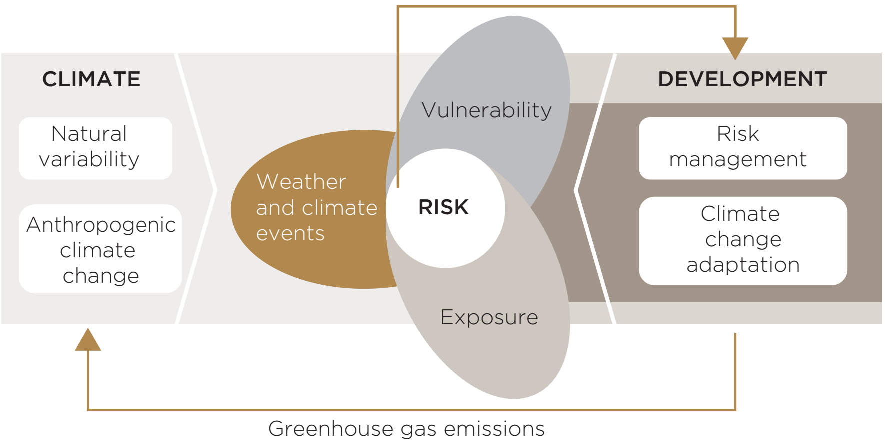


Figure 4 - Risk Dynamics – Relationship between Climate and Development.
Source: Own elaboration based on IPCC (2012).

Therefore, climate change adaptation and climate risk management become development issues, i.e., they cannot be considered merely environmental issues.

However, in the processes associated to disaster management, risks are always associated to the likelihood of occurrence of negative consequences, damages and losses (e.g., interruption of economic activity) resulting from the interaction between natural or human-induced hazards and vulnerable conditions. The effort of reducing vulnerability is the main common element of the climate change adaptation and risk management approaches. It is, therefore, the foundation for defining strategies and outlining actions for private and public institutions.

In the context of climate change adaptation, several definitions and concepts of vulnerability were developed and discussed. One of the main definitions is the one found in the IPCC Fourth Assessment Report (2007), which describes vulnerability as a function of exposure to impact, sensitivity and adaptive capacity, as shown by Figure 5.

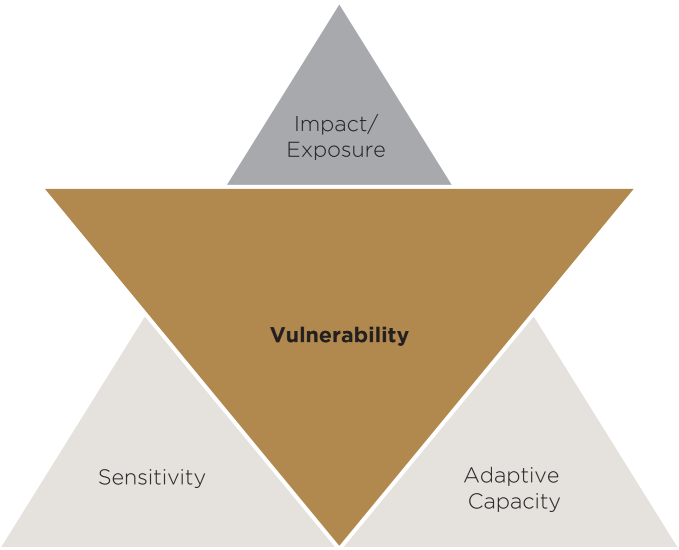


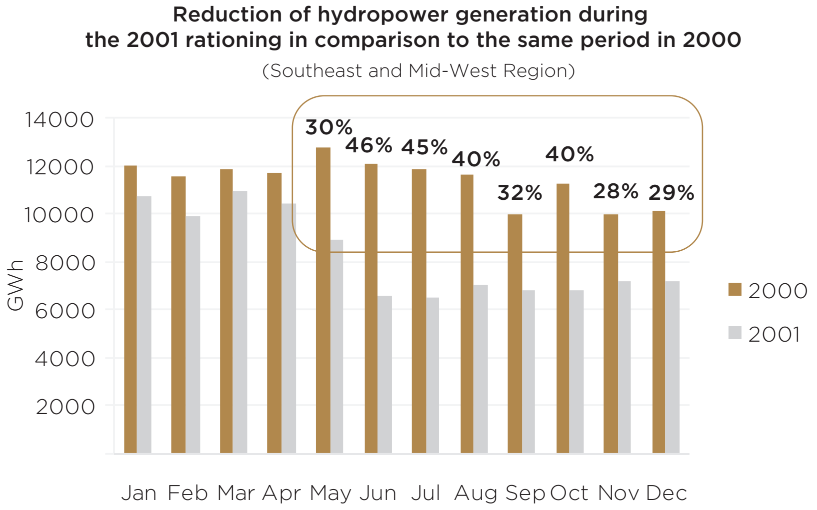
Figure 5 - Vulnerability diagram.
Source: IPCC, 2007.

> VULNERABILITY is the degree to which a system, location or socioeconomic activity is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, as well as its sensitivity and adaptive capacity.

The concept of impact adopted in this paper is connected to the effects of climate change on human and natural systems. But the concept adopted for the adverse effects of climate change is associated to the change in the physical environment or biota resulting from climate changes that have significant adverse effects on the composition, resilience or productivity of natural and managed ecosystems, on the operation of socioeconomic systems or on the health and well-being of human beings.

Climate impacts on hydropower occur when any condition affecting outflow is altered. Thus, hydropower operation is and will be indirectly affected whenever air temperatures, humidity or wind patterns are affected by climate changes. Nevertheless, the direct condition variables of change in hydropower production are basically the amount of river flows and the dynamics of reservoir management.

An example of how adverse climate effects can affect electricity generation is the drought experienced by Brazil, which led to national energy rationing in 2000 2001. In addition to other decisive factors for the period generally known as the "large blackout", as (and mainly) the lack of investments in expansion, generation and transmission in the power industry, the drought was one of the causes of the reduction in hydropower production in the period, which varied from 28 to 46 %, in comparison to 2000. Figure 6 shows the monthly variations in electrical energy production in 2001.


Reduction of hydropower generation during the 2001 rationing in comparison to the same period in 2000

(Southeast and Mid-West Region)

Figure 6 - Reduction of hydropower generation from 2000 to 2001.
Source: Own elaboration based on ONS (2012).

The magnitude and frequency of events with potential risk must be considered in sectoral vulnerability analyses on climate change. The next section will examine the characteristics of the hydropower-based electrical energy industry in Brazil, a step required to conduct the vulnerability analysis.

> Therefore, climate change adaptation and climate risk management become development issues, i.e., they cannot be considered merely environmental issues.

Chapter 3

Outline of the electrical power industry in Brazil

Today around 14 % of Brazil's energy supply mix and about 80 % of its electricity supply comes from hydropower sources, as seen in Figures 7 and 8, respectively.

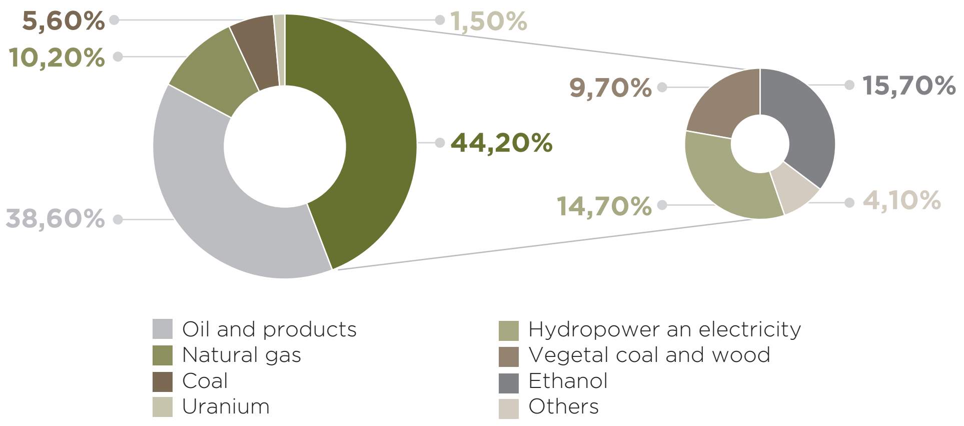
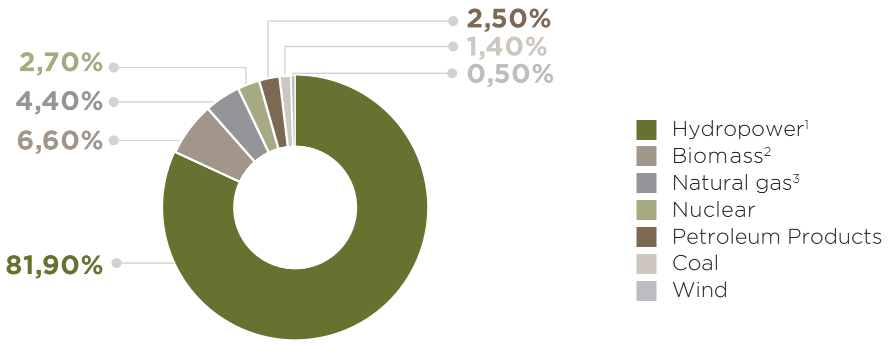


Figure 7 - Composition of the Brazilian Energy Supply Mix – 2011.
Source: EPE, 2012.



[1] Includes electricity imports. [2] Includes firewood, sugar cane bagasse, black liquor and other recovery liquids.
[3] Includes coke-oven gas.

Figure 8 - Composition of the Brazilian Electricity Supply Mix – 2011.
Source: EPE, 2012.

As to the installed capacity, in 2010, 68 % of the energy came from hydropower plants (HPP), 3 % from small hydropower plants (SHP - up to 30 MW) and 0.2 % from mini hydropower plants (MHP - plants up to 1 MW) (EPE, 2012), as shown by Table 1.

Table 1 - Installed capacity of electrical power generation (MW)

PLANTS	2006	2007	2008	2009	2010	2010 (%)
HPP	72,005	74,937	74,901	75,484	77,090	68
TPP	20,372	21,229	22,999	25,350	29,689	26
SHP	1,566	1,820	2,490	2,953	3,428	3
MHP	107	112	154	173	185	0
TNP	2,007	2,007	2,007	2,007	2,007	2
WIND	237	247	398	602	927	1
PHP	-	-	-	-	1	-
Total	96,294	100,352	102,949	106,569	113,327	100

Note: HPP – The Brazilian share of Itaipu is included (6,300 MW until 2006, 7,000 MW since 2007).
HPP: Hydropower Plant, TPP: Thermal Power Plant, TNP: Thermonuclear Plant; PVP: Photovoltaic Plant; WIN: Wind Farm; MHP: Mini Hydropower Plant; SHP: Small Hydropower Plant.
Source: ANEEL, 2012a.

In absolute terms, according to EPE (2011), electrical energy consumption in Brazil will grow around 5 % a year, going from an annual consumption of 41,197 thousand tep (479,121 GWh) in 2010 to 62,786 thousand tep (720,201 GWh) in 2020 (Table 2).

Table 2 - Final energy consumption for the main energy sources.

	2010		2015		2020		Annual variation (%)		
	10 tep	%	10 tep	%	10 tep	%	2010 -2015	2015 -2020	2010 -2020
Natural Gas	19,103	8.0	28,044	9.6	42,000	11.3	11.1	8.4	9.8
Coal and coke	10,432	4.4	15,317	5.2	18,467	5.0	9.3	3.8	6.5
Firewood	17,563	7.4	19,429	6.6	21,528	5.8	2.4	2.1	2.2
Charcoal	5,607	2.4	7,237	2.5	7,736	2.1	7.0	1.3	4.2
Sugar cane bagasse	31,930	13.4	40,001	13.7	50,698	13.6	6.5	4.9	5.7
Electricity	41,197	17.3	49,980	17.1	62,786	16.9	5.1	4.7	4.9
Ethanol	12,291	5.2	20,931	7.2	32,336	8.7	12.5	9.1	10.8
Biodiesel	2,093	0.9	2,563	0.9	4,581	1.2	5.3	12.3	8.8
Others	7,570	3.2	10,256	3.5	13,217	3.6	7.0	5.2	6.1
Petroleum products	89,910	37.8	98,660	33.7	118,656	31.9	3.1	3.8	3.4
Diesel oil	39,776	16.7	48,694	16.7	60,857	16.4	5.3	4.6	4.9
Fuel oil	6,540	2.8	7,787	2.7	8,953	2.4	3.9	2.8	3.4
Gasoline	19,009	8.0	13,993	4.8	16,690	4.5	-4.0	3.6	-0.3
LPG	8,186	3.4	9,038	3.1	10,087	2.7	2.5	2.2	2.4
Kerosene	3,674	1.5	4,524	1.5	5,834	1.6	5.3	5.2	5.3
Other petroleum products	12,724	5.4	14,624	5.0	16,234	4.4	3.7	2.1	2.9
Final energy consumption	237,697	100	292,418	100	372,004	100	5.6	4.9	5.3

Source: EPE, 2011.

Similarly, the absolute estimated consumption for 2020 for the industrial sector is where the largest increase will occur (Table 3). The industrial and commercial sectors together will represent an absolute consumption increase of around 140 thousand GWh in 2020. Currently, the industrial sector consumption alone represents 44 % of all the electrical energy consumed in Brazil (EPE, 2012).

Table 3 - Grid electricity consumption per class (GWh and %).

Year	Residential	Industrial	Commercial	Others	Total
2011	112,690	193,437	74,102	61,210	441,439
2015	135,682	229,870	93,495	70,723	529,769
2020	166,888	283,707	123,788	84,709	659,092
Period			**Variation (% p. a.)**		
2010-2015	4.8	4.6	6.2	3.7	4.8
2015-2020	4.2	4.3	5.8	3.7	4.5
2010-2020	4.5	4.4	6.0	3.7	4.6

Source: EPE 2011.

Electricity consumption in Brazil is concentrated in the Southeast and Midwest regions and it is estimated that by 2020 it will represent more than 58 % of the domestic total, as seen in Table 4.

Table 4 - Grid electricity consumption per subsystem (GWh).

Year	Subsystem				NIS	Isolated Systems	Brazil
	North	Northeast	Sou-theast/ MW	South			
2011	31,058	62,876	266,154	74,259	434,346	7,092	441,439
2015	46,780	76,466	317,967	86,653	527,866	1,903	529,769
2020	68,837	96,814	385,447	105,500	656,598	2,494	659,092
Period			**Variation (% p. a.)**				
2010-2015	10.7	5.2	4.6	4.1	5.1	-22.6	4.8
2015-2020	8.0	4.8	3.9	4.0	4.5	5.6	4.5
2010-2020	9.3	5.0	4.3	4.1	4.8	-9.6	4.6

Source: EPE, 2011.

Figures 9, 10 and 11 show that hydropower generation plants are concentrated in the Paraná and East/Southeast Atlantic basins, coinciding with the borders of the Brazilian industrial area.

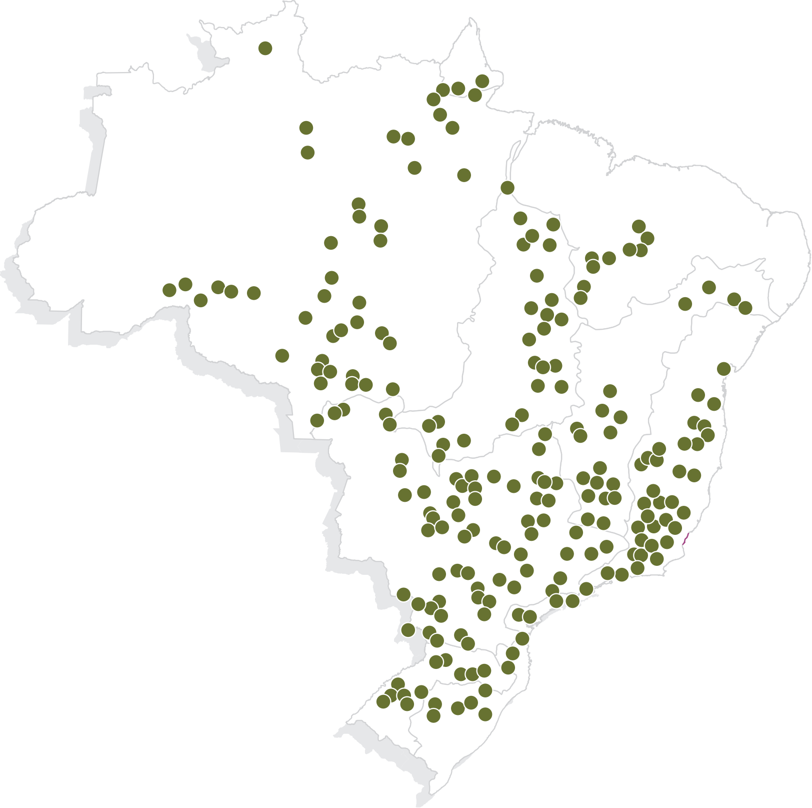


Figure 9 - Distribution of HPPs in Brazil per basins – 2011.
Source: ANEEL, 2012b.

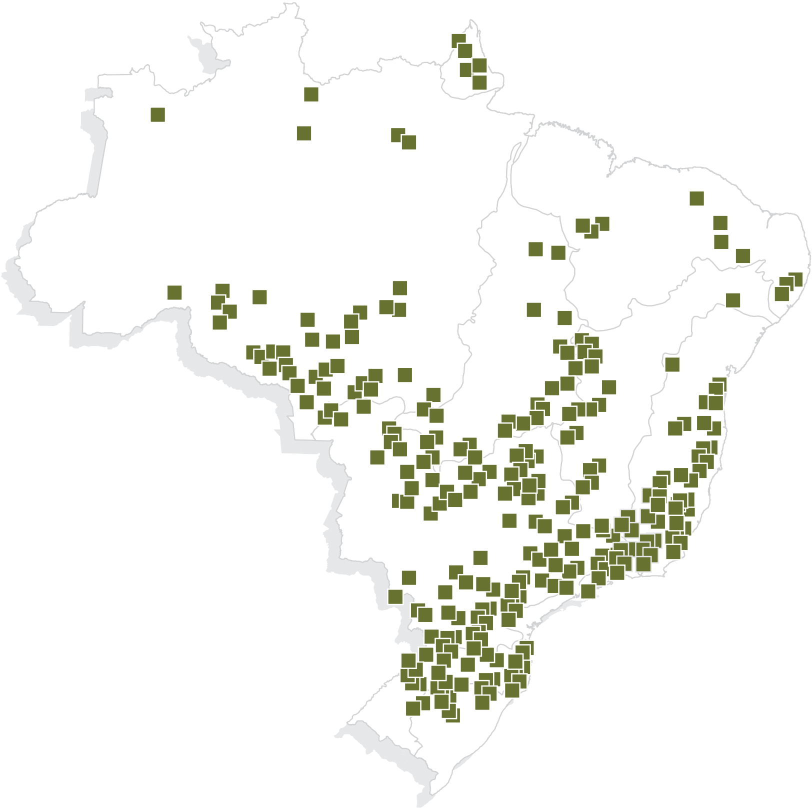


Figure 10 - Distribution of SHPs in Brazil per basins – 2011.
Source: ANEEL, 2012b.

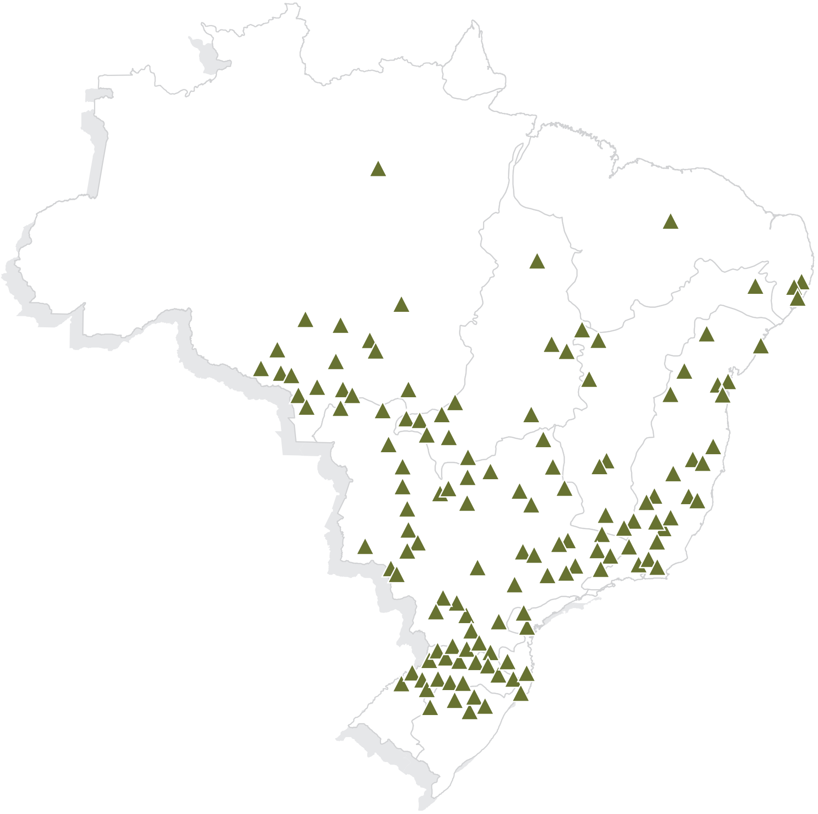


Figure 11 - Distribution of MHPs in Brazil per basins – 2011.
Source: ANEEL, 2012b.

Given the significance of hydropower in Brazil's electricity supply mix and the vulnerability of this source to climate variations and changes, the next sections will address the issue of climate variability and vulnerability of hydropowers, underlining the importance of risk management.

> Today around 14 % of Brazil's energy supply mix and about 80 % of its electricity supply comes from hydropower sources, as seen in Figures 7 and 8, respectively.

Chapter 4

Vulnerability analysis: climate risk management in the hydropower sector

In defining actions for adaptation to climate change, planners and managers must understand the degree of sensitivity of their activities to the impacts arising from these changes. Furthermore, the capacity of the production system in reacting to these impacts must be known, i.e., what will be the adaptive capacity of the managed system. Understanding the vulnerability of the managed system and the likelihood of the hazard, it will be possible to understand the associated risks.

These risks will come from daily, seasonal and annual natural climate variability, as well as from regional and global climate change. Climate change is a long-term alteration, while climate variability is a natural event that tends to occur in cycles. Annual variability records in time series show certain characteristics in the temporal behavior that can be used to examine the past climate, describe the present climate and also forecast future extreme variations and movements. This basis will provide input for the analysis of the options for adaptation within the climate risk management system.

As seen in the previous section, the hydropower system provides more than 80 % of Brazilian electricity, contributing significantly to social welfare and economic growth. Nevertheless, extreme or unexpected hydroclimatic variability, such as droughts and floods, can lead to risks for organizations, negatively affecting or even completely interrupting energy generation. Decreased energy generation can have serious social, economic and ecological impacts when societies are unable to predict, adapt or respond to these conditions.

Climate risk management provides the necessary tools and knowledge to improve traditional management methods in the hydropower sector, integrating innovation and evolution in the understanding of regional and global climate systems. Traditionally, plans to regulate hydropower systems were based completely, or almost completely, on historical hydrological records. For example, studies continue to rely on critical period hydrology, in which managers determine the yield of a system based on system reliability when confronted with the worst drought on record (Brown, 2010). In general, decision making during less severe drought periods lacks explicit consideration of risk.

Traditional approaches rarely utilize recent advances in the understanding of the climate systems or the resulting improvements in the ability to predict climate across various time scales. It must be emphasized that much of hydrologic variability is driven by climate dynamics.

Climate variability and change occur across multiple time scales and affect decision making on water resources. For example, a flood may occur over a period of hours, whereas a drought may unfold over a period of months or years. The effects of such events may be impacted by decisions made at both the operational and planning levels.

As perception of longer-term climatic variability and the potential effects of global climate change increases, managers are increasingly motivated to implement policies for risk-based decision making.

• Climate variability and flow of rivers

Climate science has advanced significantly in the ability to understand climate and it is also making progress in models that support projections of long-term human-induced climate change. However, the translation of impacts on different scales, in particular from the global to the local, represent one of the biggest challenges for climate modeling. Therefore, when we analyze vulnerabilities of specific undertakings, the role of global models tends to be reduced, in order to leave room for a better representation of the local complexity from the perspective of historical climate variability. For example, Figure 12 shows the historical variations in daily flows of a river located in the Paraná Basin (Brazil) in the period from 1937 to 2010.

> Extreme or unexpected hydroclimatic variability, such as droughts and floods, can lead to risks for organizations, negatively affecting or even completely interrupting energy generation.

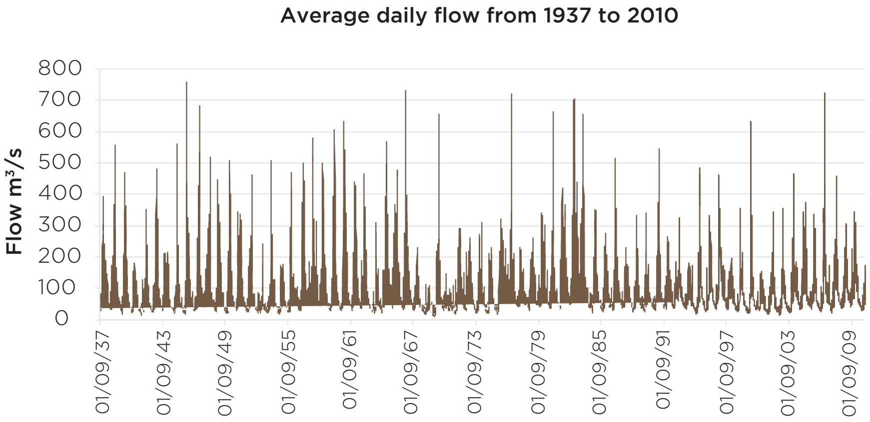


Figure 12 - Historical variations of the daily flow of a river located in the Paraná basin.

Source: Own elaboration based on ONS (2012).

Knowledge of climate variability can often provide information on the probable monthly flow conditions or even seasonal ones. Figure 13 shows the behavior of the average natural flow of the same river analyzed in Figure 12, but with data since 1931. Averages were grouped into three categories and the mean minimum and maximum flows observed were calculated, as was the simple average of all the data made available by the National System Operator (ONS).

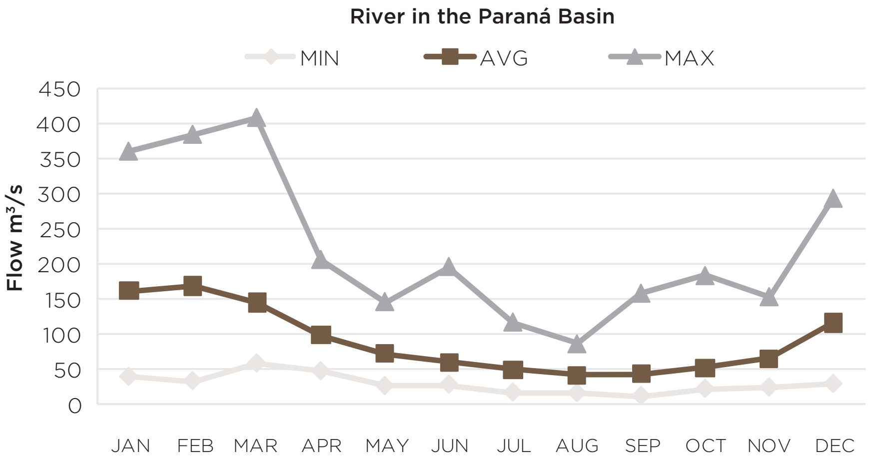


Figure 13 - Historical variations of the average monthly flow (m /s) of a river located in the Paraná basin.

Source: ONS,2012.

With appropriate information, these flow variations can be translated into inputs for the planning of turbine flow for power generation. In turn, this information allows managers to improve planning of usable flows and power generation, possibly obtaining significant improvements in the use of historical records of natural flows.

The appropriate use of monthly, seasonal and other climate variability data can improve hydropower management in current conditions, contributing to the adaptation of systems to the conditions of changes..

- **Use of information on climate variability to manage risks and opportunities: case study**

Climate change and variability can create a series of risks and opportunities for hydropower systems. Managers are responsible for minimizing risks and maximizing the benefits of a system.

Although climate information is just one input to decision-making, it can have a significant effect on the results of a hydropower system. The size of the impact on the hydropower sector in 2020 and 2050 will depend on the likelihood of occurrence and intensity, as well as on the susceptibility of the exposed elements, based on the physical, social, economic, managerial and environmental conditions of a specific analyzed context.

Given the extreme amplitude of the uncertainties of global climate models, the Brazilian territorial/water diversity and the wide range of characteristics of power plants (if we count HPPs, SHPs and MHPs, Brazil has more than 900 operating plants), this paper adopted the methodology of the climate risk management approach to three real cases. Estimates and case selection were based on a broad review of both relevant literature and the natural flow and energy generation data made available by ONS and ANEEL, respectively.

The selection of these cases allowed the development of a study of this type on climate change, given the need to quantify the impacts caused by climate change on hydropower plants and the impacts on hydropower generation from changes in the stream flow where each plant is located. Ideally, the application of the methodology to each of the 948 operational power plants would bring the highest level of detailing for the study.

Therefore, the selection of the three cases was steered by the availability of public data, which allowed a deeper analysis of the issues raised by the management model presented in this paper. The three plants are located in two of the main Brazilian water basins. The two basins chosen represent more than 60 % of the Brazilian installed capacity and more than 50 % in number of power plants. These plants are also located in the region of highest electricity consumption in Brazil and the characteristics of the plants are representative in terms of production scale and installation arrangement.[2]

Plant A is a run-of-river hydropower plant with an installed capacity of around 30MW, Plant B has about 100 MW of installed capacity and Plant C has an installed capacity greater than 1,000 MW. Both Plant B and Plant C have reservoirs in their production complex.

The subsections below show the results applied to each case study, firstly to the 2020 scenario - associating it to the natural variability - and later to 2050, incorporating two change scenarios (moderate change and extreme change), based on natural and historical variability.

Vulnerability Analysis - 2020

In this subsection the degree of exposure of the plant to the historical and current conditions of climate variability will be assessed. To stay on the safe side and for simplification, the scenario adopted for 2020 was built using the climate variability recorded from 1931 to 2010 of the monthly natural flow of the river used by the run-of-river power plant adopted as an analysis parameter. 948 points of historical flow were analyzed, reflecting the actual condition of the data made available by the National System Operator, mixing historical measurements for the river with indicative analyses when there was no anthropogenic intervention.

In order to confer reliability on the results, the flow data was depicted in a box plot, so that the simple average could be examined. The adoption of this technique is justified by the fact that hydropower production often varies over time. The processes of generating surplus or deficits of global averages generate results of surpluses or losses of the expected amounts. Thus, the application of the simple average (shown in Figures 14, 18 and 23) as a means of analysis classification should be seen merely as a reference, since risk conditions occur when the real flows are very different from the average in question. Therefore, 50 % of the results found are within the limits of each box (the small rectangles found in Figures 14, 18 and 23), statistically representing the universe of data classified between the 1st and the 3rd quartile. The vertical lines represent the amplitude of occurrence of data in a confidence interval of 99 %.

An important concept used to assess the sensitivity of a power plant is the usable flow, that is, the flow that goes through the turbine of a hydropower plant and is used to generate energy. Another important factor is the assured power, which is the contractual definition of the amount of energy that a certain power plant generates.[2]The power output of a hydropower plant per unit of usable flow is called its productiveness and varies as a function of the plant's gross head and is expressed in MW/m^3/s. To transform the installed capacity (MW) in electricity sold per month

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[2] For ethical reasons, the names and locations of the power plants remain confidential.

[3] According to ABRADEE (2012) the "assured power of each plant is a fraction of the total generating capacity of the National Interconnected System and the remuneration of the plant is based on this definition, regardless of the amount of energy effectively generated".

(GWh/month), it must be multiplied by the number of hours of a month.

PLANT A – run-of-river plant with about 30 MW of installed capacity

- **Impact and exposure - 2020**

Figure 14 shows that there is a greater natural variability of flows in the months of January, February and March and a smaller variability recorded in the months of July, August and September. Variability increases again in the month of December. Thus, the location of Plant A has conditions of great variability, and the smallest monthly average recorded was 12 m³/s, in July, while the largest historical amount recorded was 408 m³/s, during the month of March.

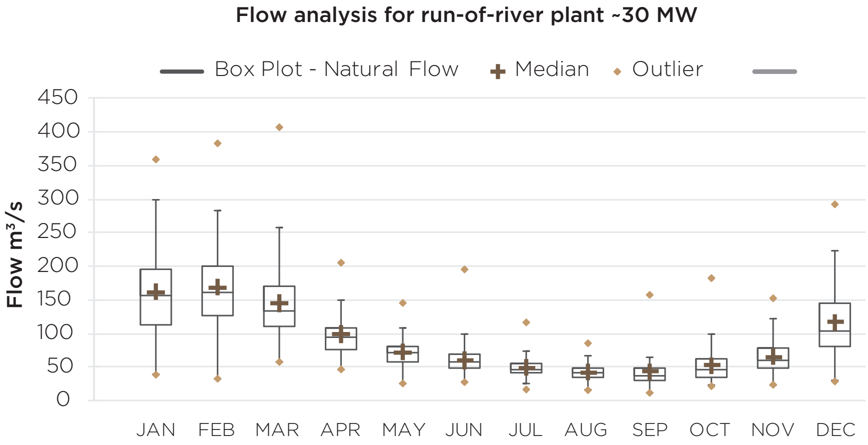

Figure 14 - Flow analysis for the run-of-river power plant.
Source: Own elaboration.

- **Sensitivity analysis for Plant A:**

The usable flow of Plant A is 178 m³ per second, that is, the maximum possible use of the river flow for producing energy in the plant. Plant A has an average assured power of 15 MW. Although the plant has operational conditions to produce double this amount, the energy to be given to the national power grid was planned for about 50 % of its capacity. The productiveness of Plant A is 0.18 MW/m³/s.

Based on the analysis of the historical flow (average monthly flow shown in Figure 14) and the average monthly energy production of Plant A during its actual operation from 1993 to 2012 (Figure 15), it is possible to determine a correlation of R2=0.9599 (Figure 16).

> Climate science has advanced significantly in the ability to understand climate and it is also making progress in models that support projections of long-term human-induced climate change.

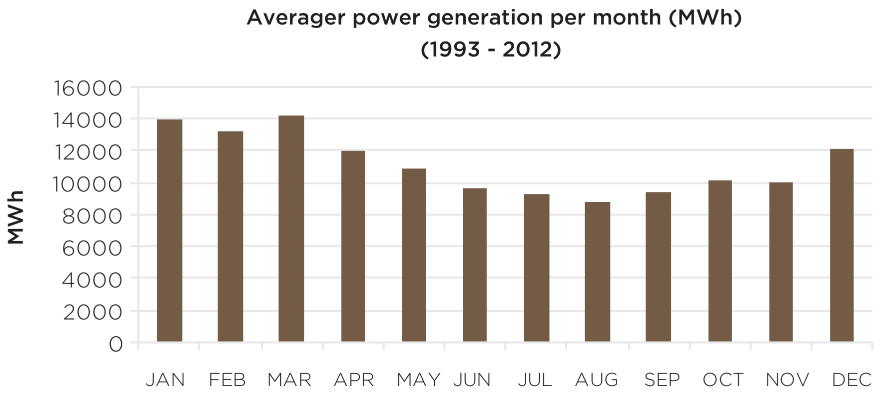

Figure 15 - Average monthly energy production of the run-of-river power plant.
Source: Own elaboration.

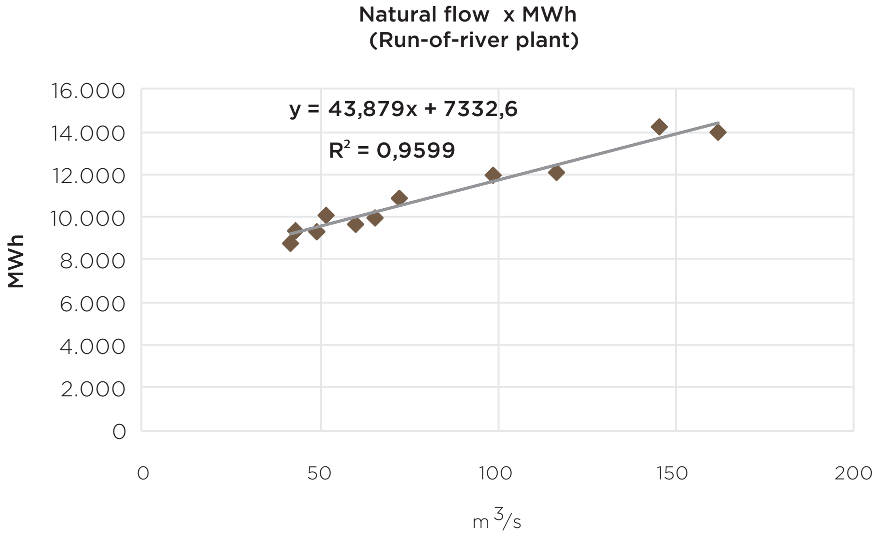

Figure 16 - Correlation Flow vs. Energy Production of a run-of-river power plant.
Source: Own elaboration.

This result shows that the sensitivity of a hydropower plant with the characteristics of Plant A, a run-of-river power plant, has a strong correlation to the variation of the river flow. In other words, although there are other significant climate variables to assess the impact on water management for electricity production, such as rainfall and rate of evaporation, in this case, these have smaller cause and effect relation. Similarly, the operational structure is based on flow energy; thus the sensitivity conditions of this power plant with respect to flow variations are more significant, comparatively reducing the margin for adaptive capacity. Finally, the statistical basis of the analytical model employed is consistent, increasing the reliability of the outcomes used to provide inputs to the assessment of the impacts on Plant A's production in other scenarios.

- **Production variations and the vulnerability of Plant A**

In this stage, we analyzed how the production dynamics would be affected by the crossing of the various scenarios drawn up from the natural flow variability data. This analysis also uses the vulnerability conditions of Plant A associated to the sensitivity conditions shown in the previous subsection.

Figure 17 consolidates the main results of energy generation according to historical data. The light gray area in Figure 17 shows the interval between the maximum generating capacity (upper limit) and the minimum assured power generation, translated into MWh. The adoption of this unit (MWh) applied to the monthly condition will allow this data to be used in the next section to quantify the impact on energy security in each of the plants.

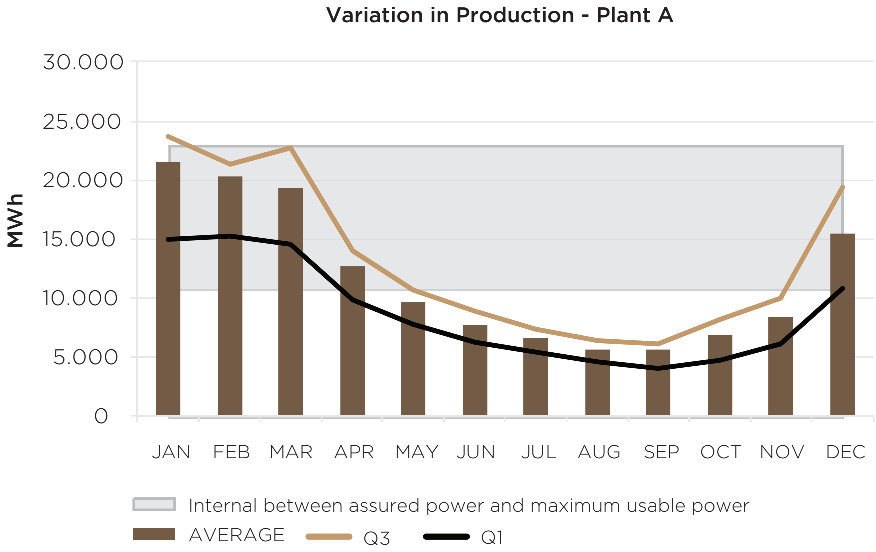

Figure 17 - Variation in energy production of a run-of-river power plant.
Source: Own elaboration.

The brown columns in Figure 17 show the average monthly generation based on the average monthly flows in the period from 1931 to 2010. The black and light brown lines correspond, respectively, to the limits of the 1st and the 3rd quartiles of the monthly flows. Therefore, the results between the two lines represent 50 % of the occurrences of the entire universe of analyzed data.

From the results, it can be seen that according to the variability data, in 2020, Plant A will tend to generate an amount substantially greater than its assured power in five of the months of the year (December, January, February, March and April). On the other hand, applying the historical monthly average, Plant A will generate and deliver to the national grid, during the remaining seven months of the year, a smaller amount than the assured power.

PLANT B – has a reservoir and around 100 MW of installed capacity.

- ### Impact and exposure - 2020

Figure 18 shows greatest natural variability of the flow in the months of January, February and March, while a smaller variability is seen in the months of July, August and September. This variability increases again in the month of December. Thus, the location of Plant B shows extreme variability conditions, and the lowest monthly amount recorded was 21 m^3/s, in September, while the largest historical amount was 270 m^3/s in March.

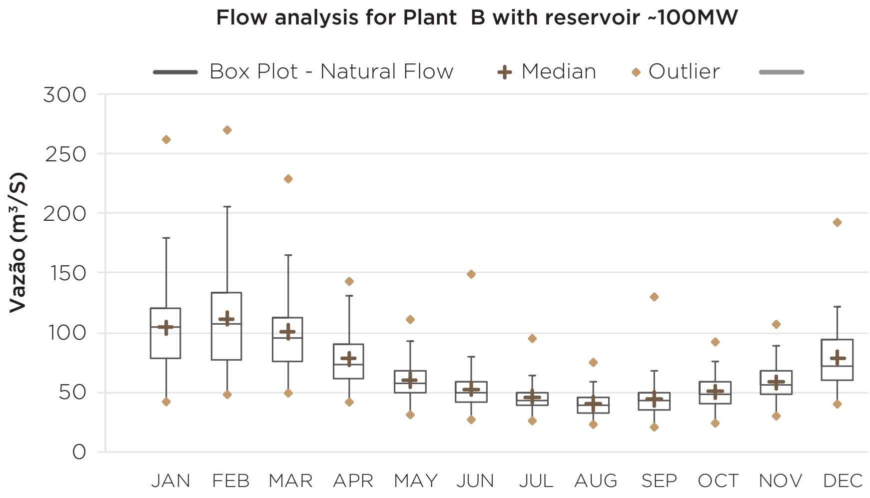

Figure 18 - Flow analysis for Plant B with reservoir.
Source: Own elaboration.

- ### Sensitivity Analysis for Plant B:

The usable flow of Plant B is 120 m^3/s and its average assured power is 50 MW, that is, although the plant has the operational conditions to produce double the power, it was planned to have around 50 % of its capacity delivered to the national electricity grid.

The productiveness of Plant B is 0.68 $MW/m^3/s$ and its average monthly energy production in actual operation from 1993 to 2012 is shown in Figure 19.

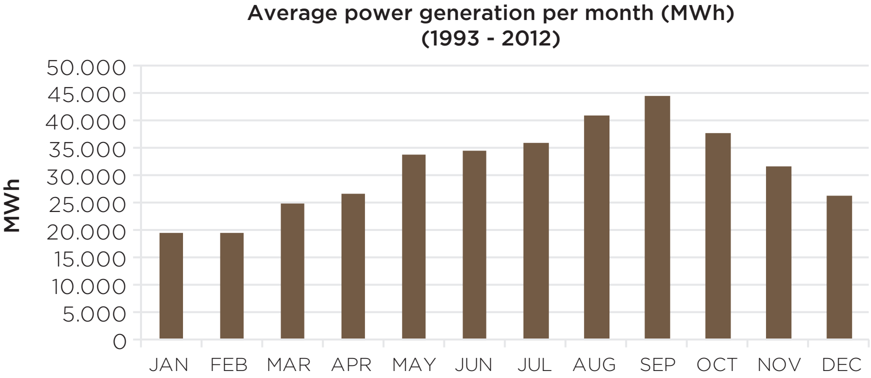

Figure 19 - Average power generation per month of Plant B.
Source: Own elaboration

> The three plants are located in two of the main Brazilian water basins. The two basins chosen represent more than 60 % of the Brazilian installed capacity and more than 50 % in number of power plants.

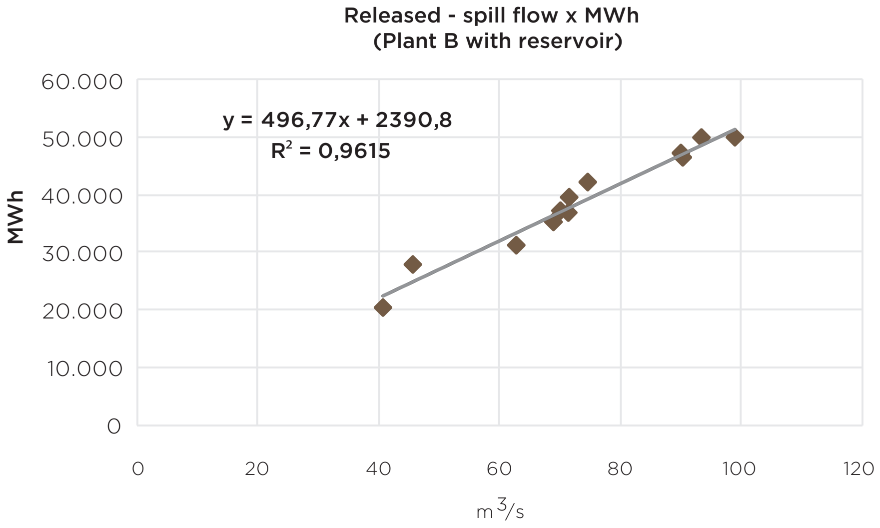

Figure 20 - Correlation Flow x Energy Production of Plant B.

Source: Own elaboration.

Therefore, the direct proportion of the variables is associated to the released flow minus the spilled flow, that is, since this hydropower plant has a reservoir, production has a strong causal link to reservoir management. Figure 20 shows that R2 is greater than 90 %.

Finally, the statistical basis of the analytical model also applied to Plant B - as for Plant A - is consistent, increasing the reliability of the outcomes used to provide input to the assessment of the impacts on production in other scenarios..

- **Production variations and the vulnerability of Plant B**

Figure 21 consolidates the main results of energy generation according to historical data for Plant B as if the results had been obtained from the river's historical flow data and if the plant used the run-of-river system. The light gray area shows the interval between the maximum generating capacity (upper limit) and the minimum assured power generation, translated into GWh. The adoption of this unit (GWh) applied to the monthly condition will allow this data to be used in the next section to quantify the impact in each of the plants.

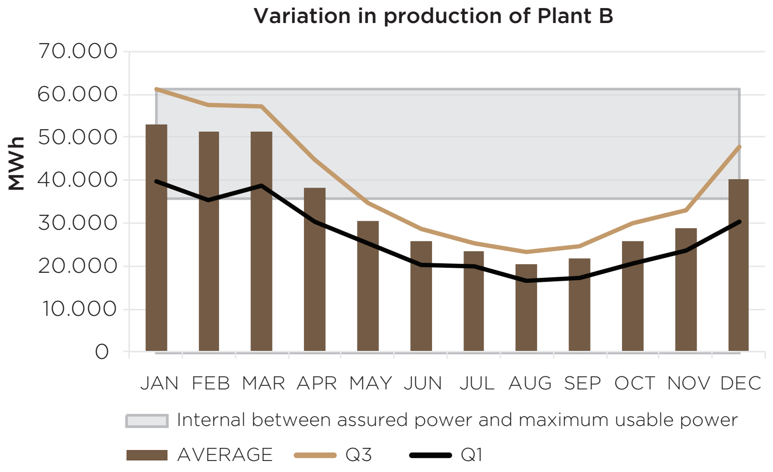

Figure 21 - Variation in energy production of a ~100 MW plant, if operated as run-of-river.

Source: Own elaboration.

The results show that if Plant B did not have a reservoir, in 2020 its behavior would be very similar to that of Plant A. Once the natural variability data was applied, it would tend to maintain an average. During five months of the year (December, January, February, March and April) it would generate an amount much higher than its assured power. On the other hand, during the other seven months of the year, using the monthly historical average, Plant B would generate and deliver to the national grid a smaller amount than the assured power.

However, the operational conditions of Plant B are quite different from those of Plant A, because its vulnerability to the natural climate variability is low due to the adaptive capacity component provided by the existence of a reservoir. This physical infrastructure condition transforms Plant B into an electricity generating unit with a stored energy component. Figure 22 shows that there is a decoupling of the dependence of the produced energy (light brown line) from the average monthly flow of the river (brown columns). The figure is based on the actual average monthly production of the last 18 years analyzed for this specific power plant.

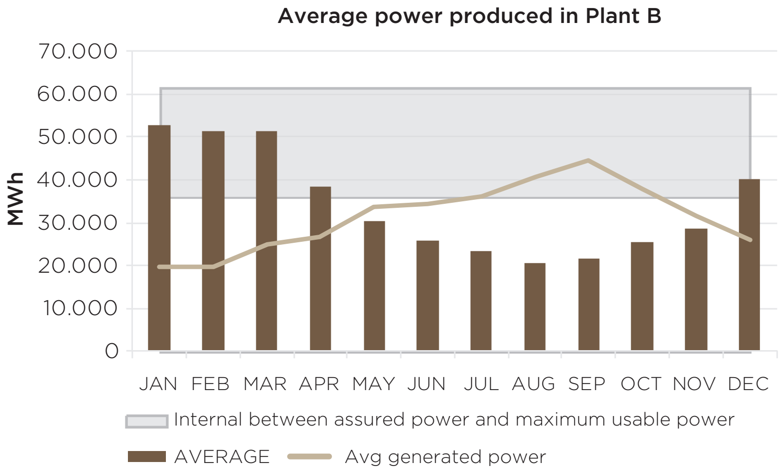

Figure 22 - Variation in actual average energy production of a ~100 MW hydropower plant with reservoir.

Source: Own elaboration.

Figure 22 shows that the highest monthly generation occurs exactly during the drought months, clearly demonstrating that Plant B has a central role in the national system since it contributes to energy security.

PLANT C – has a reservoir and an installed capacity greater than 1,000 MW

- Impact and exposure - 2020

According to Figure 23 there is greater natural variability of flows during the months of January, February and March, while a smaller variability is seen in the months of July, August and September. This variability increases again in the month of December. Thus, the location of the plant shows extreme variability conditions, and the lowest monthly amount recorded was 1,387 m^3/s in September, while the largest historical amount was 20,314 m^3/s in February.

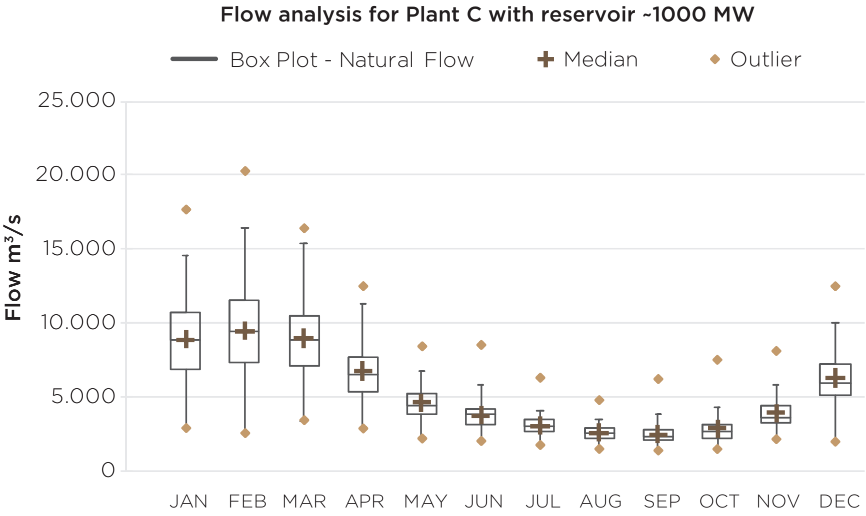

Figure 23 - Flow analysis for Plant C with reservoir.
Source: Own elaboration.

- Sensitivity analysis for Plant C:

The usable flow of Plant C is 7,960m /s and its average assured power is around 2,000 MW, that is, in percentage terms, the assured power represents about 50 % of the installed capacity.

The productiveness of Plant C is 0.36 $MW/m^3/s$, based on the analysis of historical flow. Based on the analysis of the average monthly energy production of the plant in actual operation from 2001 to 2012 (Figure 24) it can be seen, as in the case of Plant B, that there is a decoupling of the causal link of the natural flow dynamics.

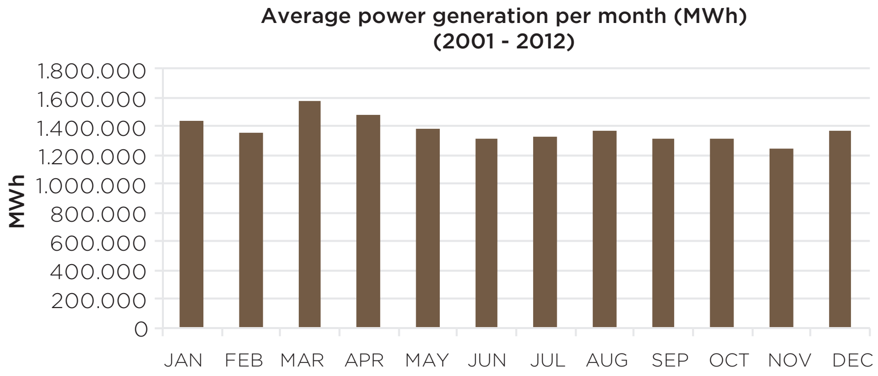

Figure 24 - Average power generation per month of the plant with reservoir.
Source: Own elaboration.

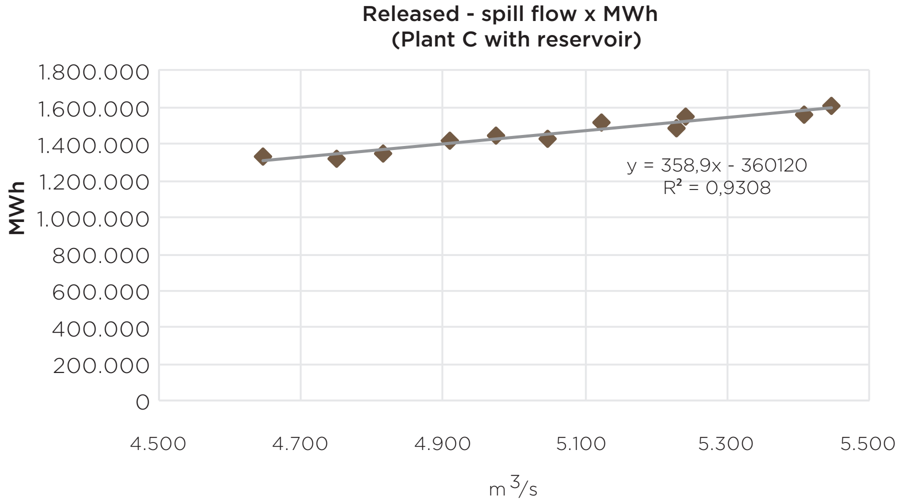

Figure 25 - Correlation Flow vs. Energy Production of a plant with reservoir.
Source: Own elaboration.

On assessing the condition of the variables, it is possible to identify a correlation of R2=0.9308 (Figure 25) when compared to the levels of released flow, minus the spilled flow, that is, the condition of reservoir management is essential for understanding the electrical production dynamics.

Finally, the statistical basis of the analytical model also applied to Plant C - as for Plants A and B - is consistent, increasing the reliability of the outcomes used to provide input to the assessment of the impacts on production in other scenarios.

- **Production variations and the vulnerability of Plant C**

Figure 26 consolidates the main results of energy generation according to the historical data for Plant C if the results had been obtained from the river's historical flow data, that is, if it did not have a reservoir. The light gray area in Figure 26 shows the interval between the maximum generating capacity (upper limit) and the minimum assured power generation, translated into MWh. The adoption of this unit (MWh) applied to the monthly condition will allow this data to be used in the next section to quantify the impact in each of the plants.

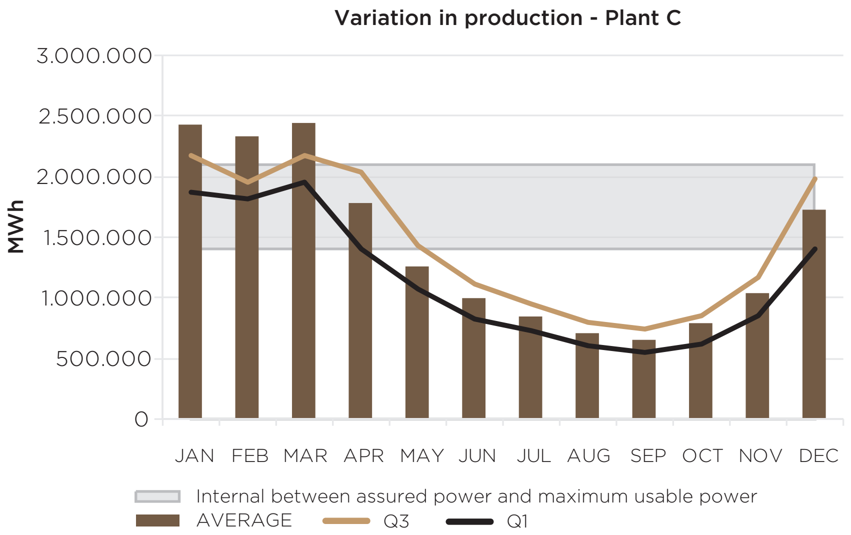

Figure 26 - Variation in the energy production of a plant with an installed capacity greater than 1,000 MW, if operated as run-of-river.

Source: Own elaboration.

The brown columns show the monthly generation averages based on the average monthly flow in the period from 1931 to 2010. The black and light brown lines correspond, respectively, to the limits of the 1st and the 3rd quartiles of the monthly flow. Therefore, the results between the two lines represent 50 % of the occurrences of the entire universe of analyzed data.

The results show that if in 2020, Plant C did not have a reservoir, its behavior would be very similar to that of Plant A. Once the natural variability data was applied, it would tend to maintain an average. During five months of the year (December, January, February, March and April) it would generate an amount much higher than its assured power. On the other hand, during the other seven months of the year, using the monthly historical average, Plant C would generate and deliver to the national grid a smaller amount than the assured power.

However, the operational conditions of Plant C are quite different from those of Plant A, because its vulnerability to the natural flow variability is relatively low due to the adaptive capacity component provided by the existence of a reservoir. This physical infrastructure condition transforms Plant C into an electricity generating unit with a stored energy component. Figure 27 shows that there is a decoupling of the dependence of the produced energy (light brown line) from the average monthly flow of the river (brown columns).

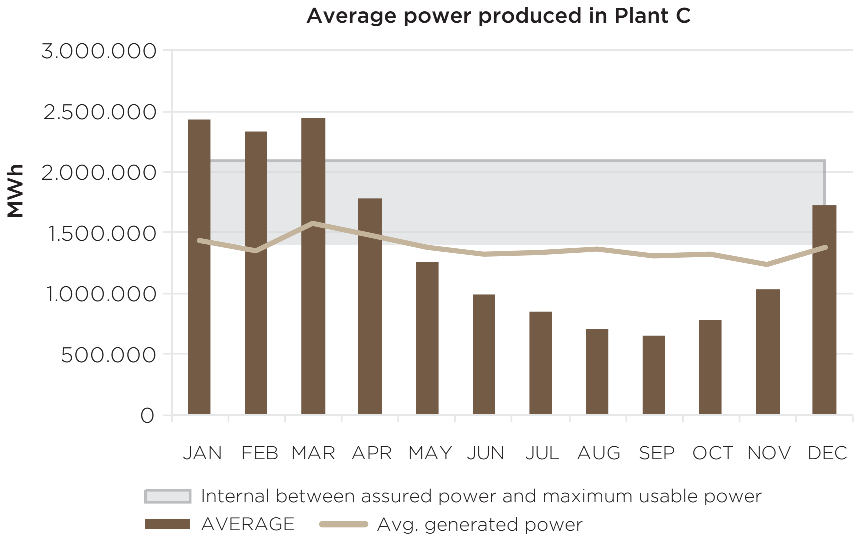

Figure 27 - Variation in energy production of a hydropower with a capacity greater than 1,000 MW with reservoir.

Source: Own elaboration.

Figure 27 shows that by regulating the flow, energy generation is practically situated within the blue area the entire year. Plant C has very regular flow, thus it has a central role in the national system, since it contributes to energy security given its large production.

4.1 Vulnerability Analysis - 2050

The exercise carried out in this section refers to the application of the climate risk approach to add the natural flow variability to the long-term climate change variable for the 2050 scenario. 2050 may be considered an extreme long-term time limit for Brazilian entrepreneurs. Nevertheless, given the lifetime of the hydropower infrastructure, this is an appropriate time frame, since the average useful life of each of the analyzed plants is greater than 50 years. Therefore, even if ownership and management changes occur over the next 38 years, it is highly likely that Plants A, B and C will be fully functional in the year 2050.

Consequently, in order to design likely change scenarios, three approaches were adopted to provide comparable results. The first scenario was defined as *zero change*, that is, we applied the condition of the historical average natural flow variability over the 80 evaluated years in the river where each studied plant is located. The other two scenarios were *change* scenarios, a *moderate change* scenario and an *extreme change* one. Given the high degree of uncertainty in applying global models to local conditions (as explained in the first section of this paper), a rate of change related to the concept of Extreme Weather Events was applied to the historical natural variability.

> *"An Extreme Weather Event is an event that is rare within its statistical reference distribution at a particular place. These definitions vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called extreme weather may vary from place to place. An extreme climate event is an average of a num-*

> *ber of weather events over a certain period of time, an average which is itself extreme (e.g. rainfall over a season)." (IPCC, 2007;[4] Marengo et. al., 2007: p.46).*

According to the Fourth IPCC Assessment Report, it is very likely that the 21st Century will see increased precipitation intensity and variability, increasing the risks of flooding.[4] Thus, to develop a moderate change scenario an aggregate average of observations was used. This aggregate was distributed homogeneously over the historical data from the 10th to the 90th percentile, respectively, on the driest and wettest months.

To define the extreme change, the same rationale of the 10th and 90th percentiles was used, but for the results of the flows calculated from the distribution of Q3 for the months of largest flows (rainy) and Q1 for the flows of the dry months.

PLANT A – a run-of-river plant with about 30 MW of installed capacity

The brown columns in Figure 28 show the average monthly potential generation based on the average monthly flows of about 80 years (1931 - 2010) of analyzed data. The the dark brown and dark gray lines represent the moderate and extreme scenarios respectively for 2050.

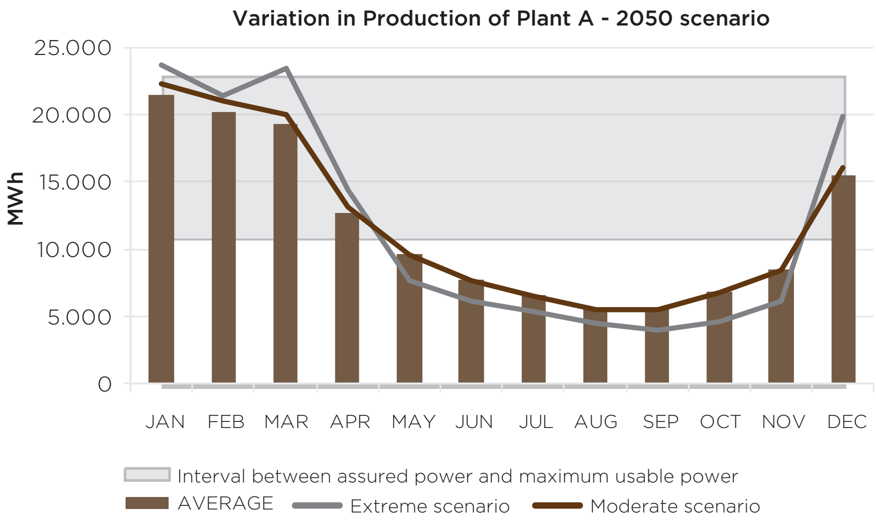

Figure 28 - Variation of energy production of Plant A in the moderate and extreme scenarios for the year 2050.

Source: Own elaboration.

On applying the natural variability data to the 2050 scenario, Plant A will tend to maintain an average, generating an amount greater than the average assured power during five months of the year (December, January, February, March and April). During the other seven months of the year, the plant would generate below its assured power. The conditions assured in these seven driest months would represent, respectively, an approxi-

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[4] IPCC glossary used in the Fourth Report of the Working Group II on Impacts, Adaptation and Vulnerability, available at:http://www.ipcc.ch/publications_and_data/ar4/wg2/en/annexessglossary-e-o.html

[5] Executive Summary available at:http://www.ipcc.ch/pdf/technical-papers/ccw/executive-summary.pdf

mate reduction of 34 % and 49 % in the moderate and extreme scenarios of the expected assured power in this period.

The productive capacity shows a similar behavior in both scenarios, reaching an increase in the average of 6.5 % in the moderate scenario and 5.5 % in the extreme one, per year.

As to the assured power, using the monthly historical average, Plant A would generate and deliver to the national grid an amount greater than the assured power. Therefore, the annual electricity generation of Plant A would not be in a critical condition. If, however, Plant A were using self-production, in both scenarios (extreme and moderate), the seven dry months would demonstrate the vulnerability of the venture in terms of energy security, because actions for adaptation and to reduce vulnerability would be required - issues that will be dealt with later on, in a specific section.

> Consequently, in order to design likely change scenarios, three approaches were adopted to provide comparable results.

PLANT B – plant with a reservoir and around 100 MW of installed capacity

With regard to the application of moderate and extreme change scenarios for 2050, an additional analysis was carried out for Plant B, as if it operated on a run-of-river system. The brown columns in Figure 27 show the average monthly potential generation based on the average monthly flows over about 80 years (1931 - 2010) of analyzed data. The blue/light brown and red/orange lines represent, respectively, the moderate and extreme scenarios for 2050, in which the dotted lines represent the analysis with a reservoir and the continuous lines the analysis with run-of-river.

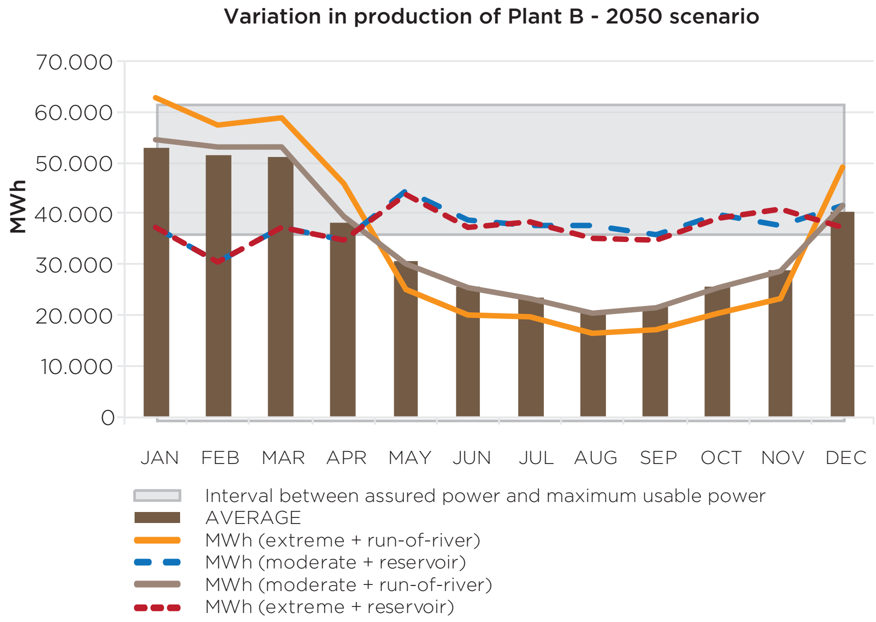


Figure 29 - Variation of energy production for Plant B for the moderate and extreme scenarios for the year 2050.

Source: Own elaboration.

The results show that Plant B has quite a different behavior from that usually ensured by the presence of reservoirs. In the moderate scenario, the generation profile of Plant B is quite similar to its extreme scenario. The similarity arises from the characteristics of the reservoir, since if it has 100 % of useful volume, it will be able to meet the demand of more than 12 full months at a rate of generation compatible with the assured power.

Managing the reservoir, in both the extreme and in the moderate scenarios, ensures the generator sufficient capacity throughout the year to move the stored volume to meet the conditions for energy security.

The situation is quite different when the scenarios are assessed for mere flow production (run-of-river). A major difference is seen between the rainy months (January, February, March, April and December), which greatly outweigh the demand to generate the assured power, and the dryer months, when it has a much lower performance with regard to the assured power. Annually, in the run-of-river case, both extreme and moderate scenarios represent a drop of approximately 4 % in the annual assured power condition, while in the situation with a reservoir, there would be an increase of 3 % and 5 % in the extreme and moderate scenarios, respectively.

The existence of a reservoir, therefore, decisively reduces the Plant B's vulnerability to natural climate variability, including under the extreme and moderate change conditions.

PLANT C – plant with reservoir and an installed capacity greater than 1,000 MW

The Plant C reservoir has a smaller storage capacity than that of Plant B. It is able to ensure the supply of the assured power for only about 45 days.

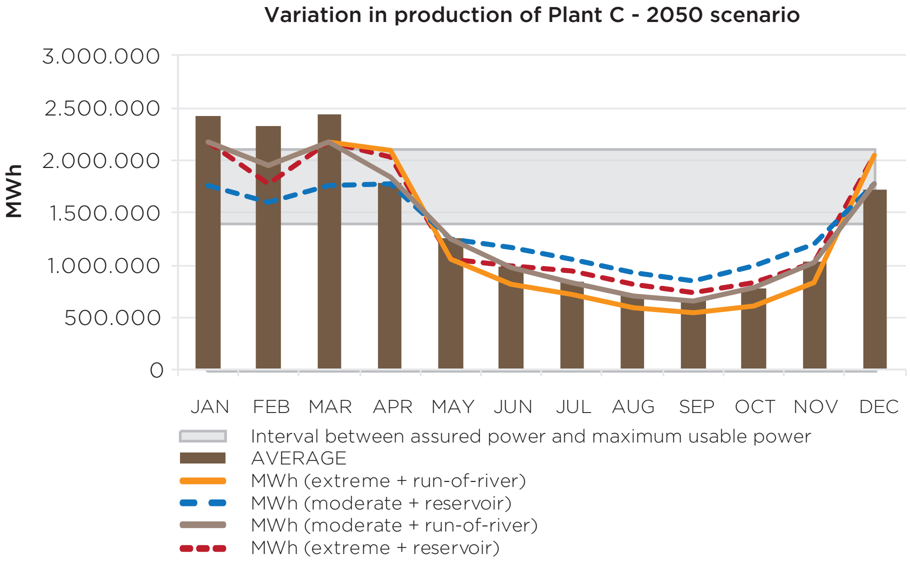


Figure 30 - Variation in energy production for Plant C for the moderate and extreme scenarios for 2050.

Source: Own elaboration.

The brown columns in Figure 30 show the average monthly generation based on the average monthly flows of some 80 years (1931 - 2010) of analyzed data. The dashed lines represent the extreme change (red) and moderate change (dark blue) scenarios for the Plant C reservoir management. As seen, the moderate and extreme scenarios generated less energy than the assured power, even when the reservoir was used in the periods of historical reduced flow (May to November). This result is even seen in annual terms, that is, the energy generated in the extreme and moderate scenarios is less than the assured power and also less than the verified production average.

The continuous brown and orange lines correspond to the moderate and extreme change scenarios, respectively, if plant C were to be fully compatible with the flow energy (run-of-river) system. In this case, the impact of electricity generation in the extreme and moderate change scenarios, particularly in those months with reduced flows, would even be greater than the reservoir scenario. The extreme scenario would reduce the total generation by about 7 % and the moderate one by about 4 %. On analyzing the situation with a reservoir, the extreme scenario would reduce total generation by about 2 %.

Therefore, Plant C is less vulnerable because of the low storage capacity of its reservoir and its profile is similar to that found in Plant C with run-of-river. This is because the vulnerability of the plant to natural climate variability is reduced due to the existence of the reservoir.

4.2 Actions for vulnerability reduction and adaptation of the Brazilian electricity sector and their relative greenhouse gas emissions

As mentioned previously, the concept of adaptation is associated to initiatives and measures to reduce the vulnerability of natural and human systems when faced with current and expected climate change effects. However, given the high degree of uncertainty of the global models, and using the climate risk management methodology, we decided to adopt the premise that the most chronic vulnerabilities are associated to natural and historical variability. Thus, in designing scenarios and in carrying out the impact and vulnerability analysis, the main focus was chosen to be the dynamics of the natural variability added to potential changes, from a perspective of extreme weather events.

Given this, it must be stated that the actions to reduce vulnerability to natural variability and climate change should be classified to be more useful for management processes. Frame 1 summarizes how these actions can occur, in both natural and human systems.

Frame 1 - Actions to reduce vulnerability.

Actions to reduce vulnerability in Natural Systems & Human Systems			
Attitude	**Time Frame**	**Responsible socioeconomic player**	**Decision-making level**
Proactive (anticipatory)	Short Medium	• Private Sector • Public Sector • Academia • Civil Society	• Public Governance • Corporate Governance • Academic Governance • Civil Society Participation • Managerial • Operational
Reactive (spontaneous)	Long		

Socioeconomic players can either prepare for the impact or react to it. Time frames for results and actions can be short, medium and long. Actions can be stimulated by the private sector, the public sector, or by representatives from academia and/or organized civil society. With regard to decision making, the various levels can be employed, from corporate governance to the operational implementation of projects.

Given the nature of the impacts on electricity generation in each of the cases, an analysis was first undertaken with a focus on energy security. Unilaterally, plants at operation and managerial levels will tend to reduce their vulnerabilities through reactive actions, i.e., acquiring energy to cover deficits in generation. In the following section, possible actions to reduce vulnerability in anticipatory and preventive manners will be dealt with in a more systemic way.

Below are the results of the monthly electricity generation reductions for each of the cases and also the alternatives available to replace the sources and their respective greenhouse gas emissions.

PLANT A – a run-of-river plant with about 30 MW of installed capacity

Figure 31 shows the monthly production distribution in the moderate (dashed dark brown line) and extreme (dashed dark gray line) scenarios of the average production seen in Plant A. Despite the surplus identified in the months of December, January, February and March in both scenarios, there is a clear shortage from April to November.

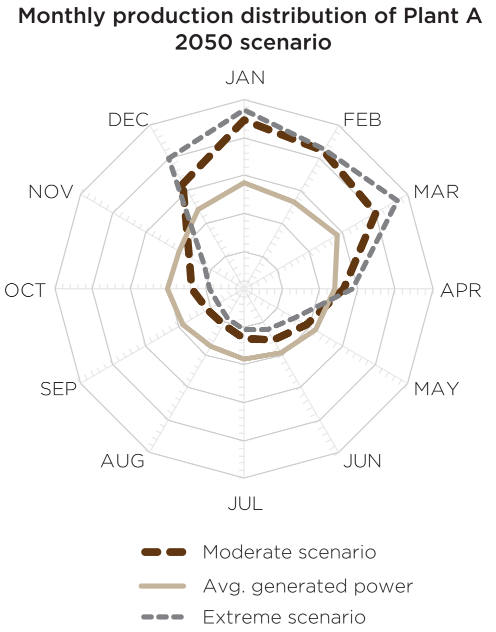


Figure 31- Monthly production distribution of Plant A in the 2050 scenarios.
Source: Own elaboration.

As to energy security, managers of Plant A are expected to cover the deficit months with other energy sources. During the decision making on the choice of the most appropriate source, the sources with the least vulnerability to natural climate conditions are considered to be fossil sources. However, these generate far more greenhouse gas emissions than Plant A, and other renewable sources. Figure 32 compares the GHG emissions

> The concept of adaptation is associated to initiatives and measures to reduce the vulnerability of natural and human systems when faced with current and expected climate change effects.

in covering the deficit in Plant A with renewable sources or thermal power plants using natural gas, fuel oil, coal and diesel. The results vary considerably: from zero, when using renewable sources up to 30 thousand tonnes of carbon dioxide equivalent (tCO_2e), in the case of coal thermal power plants, in the extreme scenario, or 15 thousand tCO_2e in the moderate scenario (projection for 2050).

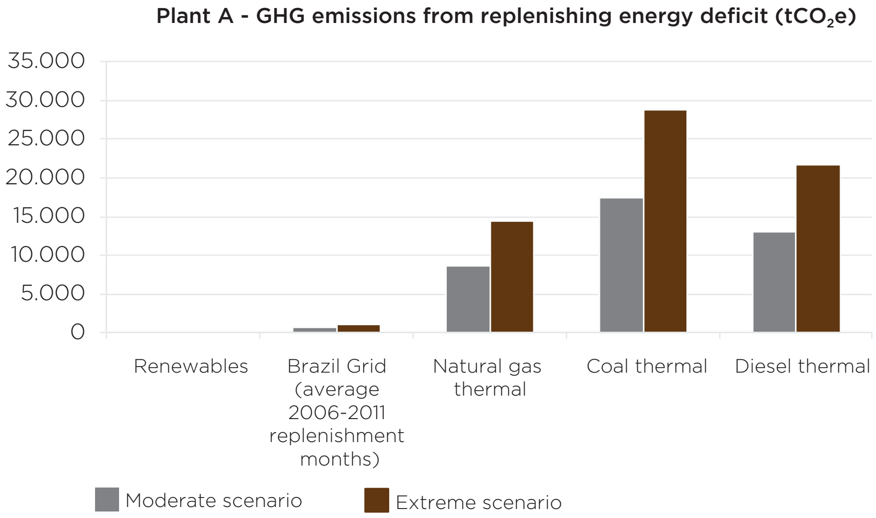


Figure 32 - GHG emissions per source from replenishing the energy deficit in Plant A.
Source: Own elaboration.

PLANT B – plat with a reservoir and around 100 MW of installed capacity.

According to Figure 33, Plant B's vulnerability is very low even with the variation of change scenarios. When compared to historical production averages (light brown continuous line), production deficits are seen in only two months, but the generated energy is still well above the assured power (about 20 % higher). Thus, the graph below, of alternatives to cover the deficit in the production average is still greater than the assured power.

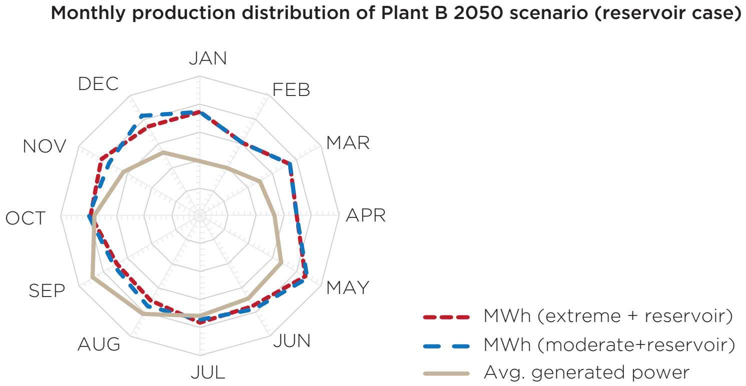


Figure 33 - Monthly production distribution of Plant B in the 2050 scenarios.
Source: Own elaboration.

The results are quite significant when compared to the results from Plant A. In the extreme scenario, the GHG emissions from substituting coal thermal power would be 15 thousand tCO_2e in the case of Plant B and around 30 thousand tCO_2e for Plant A. Plant B has an installed capacity three times greater than Plant A's, but the existence of a reservoir with a very large storage capacity means less vulnerability and lower demand for energy replacement.

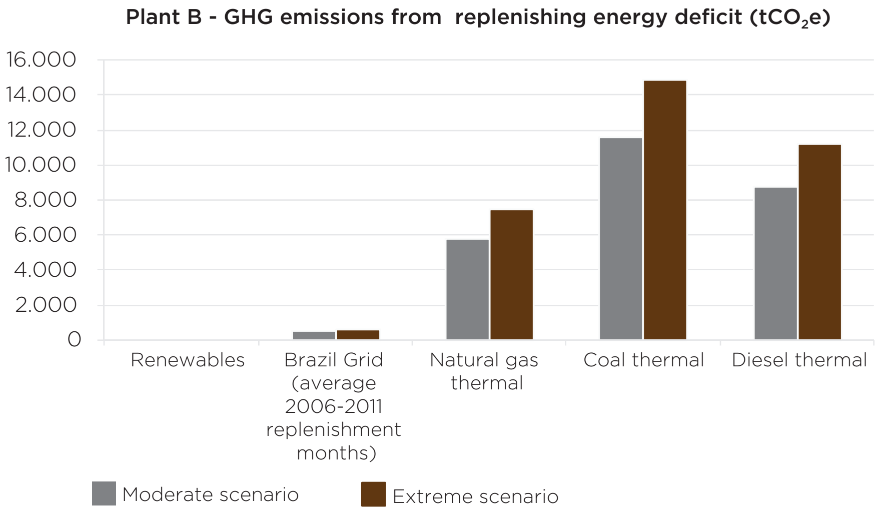


Figure 34 - GHG emissions per source for meeting energy shortage in Plant B.
Source: Own elaboration.

PLANT C – plant with reservoir and an installed capacity greater than 1,000 MW

The existence of a reservoir in itself does not ensure lower vulnerability. Figure 35 shows the results for Plant C. Although the plant has a greater capacity during the rainy months - which allows better use of increments in the extreme scenario (dashed red line) when compared to the moderate scenario (blue dashed line) - deficits occur in a similar manner to Plant A (run-of-river).

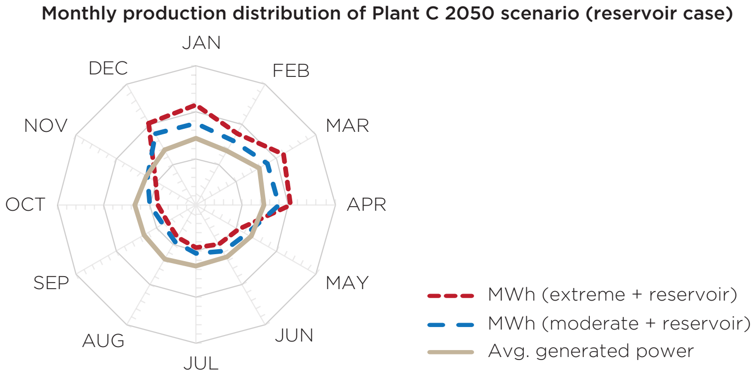


Figure 35 - Monthly production distribution of Plant C in the 2050 scenarios.
Source: Own elaboration.

Shortages can be seen in the extreme scenario from May to November and in the moderate scenario from May to October. Consequently, when we evaluate the energy sources and their respective GHG emissions (Figure 36), Plant C has a vulnerability characteristic closer to Plant A's (run-of-river) than Plant B's, which also has a reservoir. When they are compared using coal, Plant C has an emission of around 3 million tCO_2e to cover the shortage in the periods of reduced flow in the extreme scenario and about 2 million tCO_2e in the moderate one. This figure is 86 times higher than the one for Plant A, even though Plant C has an installed capacity 100 times that of Plant A's.

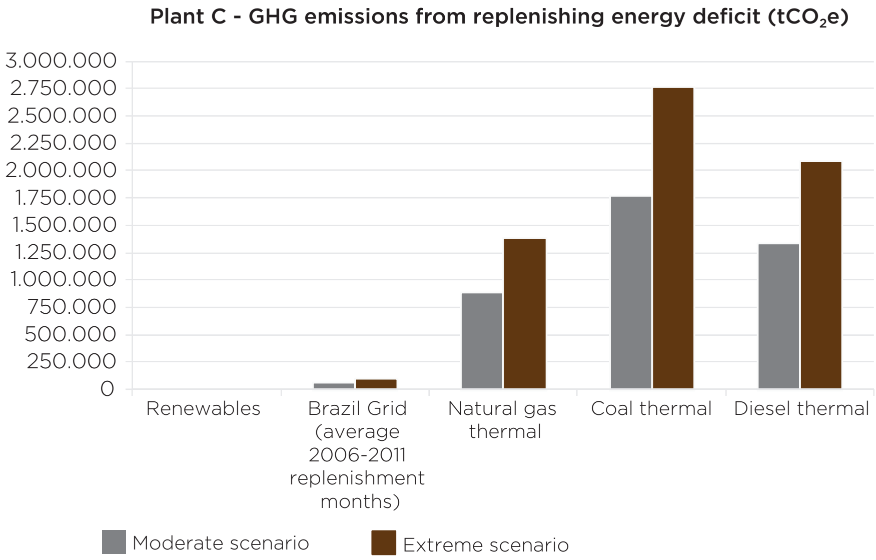


Figure 36 - GHG emissions per source for meeting energy shortage in Plant C.
Source: Own elaboration.

4.3 Main qualitative guidelines and recommendations for vulnerability reduction and adaptation actions with a systemic and preventive approach for the Brazilian electricity system

This section addresses the conditions for analysis beyond these specific case studies, taking into account the main reference material from various institutions such as universities, research centers, sectoral representative organizations, government agencies, regulating agencies and civil society organizations.

Aspects related to the main river basins that produce electricity in Brazil were also examined, but given the uncertainties of current climate models for projecting future rainfall in Brazilian river basins, associated to the need to integrate a model of the vegetation and land use dynamics to a climate model, this approach should be understood as a supplementary one.

Therefore, the recommendations included here concentrate mostly on reducing the existing vulnerability in order to expand and maintain electricity generation from hydropower sources in Brazil. As seen in the section describing the domestic electricity sector, this is the main source of electricity generation in Brazil.

Examination of the available literature indicates that the Brazilian power system has vulnerabilities to natural climate variability and to climate change, due to a tendency to lose renewable energy generating capacity, and in all regions.

In reviewing these studies, the main focus was on the aspects relevant to reducing the vulnerability of the Brazilian electricity sector and those that are directly linked to the main subjects of the National Climate Change Plan (Low Carbon Development, Renewable Energy, Biofuels, Vulnerability and Adaptation, R&D):

- **Reduce the direct dependence of hydropower generation on flows and ensure additional energy supply from other sources.**

Companies should consider the likelihood of changes in energy consumption patterns arising from global warming to be a strategic risk, in addition to existing projections. These changes will arise mostly from increased refrigeration and air conditioning use in the residential and services sectors. Furthermore, reversion of the development scenario towards the interior of the country will lead to new urban centers and new consumer markets.

The energy industry should thus seek flexible generation options, encompassing not only operational and institutional aspects, but also diversifying energy sources to reduce dependence on a single energy source. Wind, thermal solar and photovoltaic energy must be further exploited. Likewise, the recovery of biogas generated in sanitary landfills and/or sewage treatment stations, on industrial and/or residential scale should be further encouraged and fostered. In addition to this perspective, objective criteria must be defined for the use of renewable sources in the Brazilian electricity mix, taking into account not only economic factors (energy prices) but also social and environmental aspects.

The large-scale use of sugar cane bagasse also seems to be promising. Sugar cane bagasse is a byproduct of ethanol and sugar production processes. It can be used to increase the energy use of sugar cane by combined heat and power or, alternately, as input to ethanol production through hydrolysis. The availability of bagasse depends directly on ethanol and sugar production, since these are the main outputs of the plants, but the possibility of selling electricity as a byproduct to the grid can encourage sector expansion. Increase in electricity generation from the residual sugar cane biomass (bagasse, leaves and tips) depends basically on: the use of fire-less harvesting techniques, which would make leaves and tips available for electricity generation; the implementation of measures to reduce demand for steam in the industrial sugar cane conversion process; the use of more efficient energy conversion technologies; the adaptation of transmission networks for this purpose; and a regulatory framework that encourages this use.

This would foster decentralization of the energy production areas, currently concentrated in the Brazilian industrial complex, thus ensuring the development of other regions.

- **Expand the reliability of sector supply**

In addition to the physical risks related to energy generation, risks associated to energy distribution and transmission should also be considered, since studies indicate a greater incidence of strong winds, flooding, long drought periods, and torrential rains, among others. These factors can have an impact on energy transmission and distribution processes, as well as on the operation of the hydropower plant reservoirs.

In light of these risks, companies should invest in monitoring and preventive actions, such as:

- Establish an extensive monitoring network to continuously follow hydroclimatic data and analyze and study the effects of climate change;
- Implement specific flood control, in addition to carrying out daily meteorological forecasts, including storm warnings to inform and guide local communities and managers on the state of the rivers (with monitoring of levels and flows);
- Provide society at large with the operational data of companies' main reservoirs;
- Implement monitoring systems capable of detecting, processing, distributing and storing information on atmospheric discharges, assisting meteorological warnings;
- Assess operating conditions of the watersheds of hydropower plants and verifying if any operational or physical adaptation of dams is required;
- Consolidate Safety Plans and Emergency Plans of Action for the case of dam failure including: communication flowcharts, those

responsible for response actions; how an emergency is detected; and warning levels, as well as maps of the downstream flooding;

- Seek the adoption of technological alternatives for distribution networks (protected and isolated) to improve the coexistence of urban trees and overhead distribution networks, preventing trees from falling on the power lines and interrupting energy supply;
- Monitor fires to protect transmission lines, plant cover and associated biodiversity, as well as the human populations living close to power lines;
- Discuss with various stakeholders the importance of maintaining a thermal power facility to provide security for the electricity system. Although these aren't clean energy sources, they are currently part of the country's energy mix and contribute significantly to energy security during periods of extreme weather events, particularly, water shortage;
- Avoid, when negotiating the energy supply mix, establishing commitments that result in higher electricity tariffs for Brazilian consumers. They should benefit from the fact that the country has made tremendous efforts to invest in renewable sources and can, therefore, have a clean supply mix. Access to electricity services should be ensured to all and be affordable, since this guarantees social inclusion and competitiveness of Brazilian companies.

Companies should also consider the risks related to their reputation and image arising from their attitudes and actions on climate issues and adaptation to this new scenario. Companies must be transparent in their sustainability policies and actions and maintain a proactive dialogue with stakeholders. Communications should not be limited to the publication of sustainability reports and GHG emissions inventories, since many interested parties and decision makers neither have access nor understand them.

• Promote greater energy efficiency in transmission and distribution

Brazilian experience shows that between 50 and 70 % of flaws occurred in the past in Brazilian transmission lines were related in some way to climate conditions - more specifically, to intense or severe storms. With climate change, rain and wind storms will tend to increase their intensity, which will make overhead transmission lines in Brazil more vulnerable. Together or alone, these phenomena are capable of interrupting the energy flow along the lines, interfering significantly in the electricity system. Climate change acting in a region that is already fragmented by deforestation could have even greater effects on continuous forests. A fragmented forest is more vulnerable to forest fires, which are probably caused by human activity. Extreme weather events can also increase the risk of fires, allowing the fire to spread even more quickly and damage the electricity grid.

If climate change can cause problems in energy transmission, in distribution the situation is no different. Most (more than 90 %) of electricity distribution networks existing in Brazil are overhead and are concentrated in large urban areas, where most consumers live. In these areas, buildings, replacement of vegetation by asphalt, and pollution caused by cars and factories cause atmospheric alterations (such as temperature increase, increased concentration of particulate matter and slowing of winds) that favor the occurrence of strong storms.

The damage caused by lightning to distribution networks can become even more frequent given the increased number of extreme weather events. However if we consider the new distribution network model that is being adopted in Brazil - the smart grid model - it is possible to expand the resilience of the system. These grids require the establishment of an appropriate infrastructure and are based on the use of digital devices to monitor the distribution in real time and on the use of different energy sources. This transformation will occur both in the availability and consumption of energy, also resulting in energy savings.

• Encourage the rational use of energy

Brazil has developed information programs through its National Electricity Conservation Program (PROCEL), National Program to Rationalize the Use of Petroleum and Natural Gas Products (Conpet) and the energy companies. Maintaining these programs is necessary to provide continuity and regularity of the dissemination of current information on energy technologies and the most efficient ways of using them. Even so, significant obstacles exist, particularly in the diffusion of technologies for the thermal uses of solar energy in buildings and in the residential and industrial sectors. These can be overcome by constant information dissemination.

Since its creation in December 1985 until 2006, the National Electricity Conservation Program (PROCEL) invested R$ 971 million and obtained equivalent energy savings of 24,598 GWh/year, the equivalent of the output of a power plant with a capacity of 6,612 MW. Nevertheless, the more efficient use of electricity in the industrial, residential and services sectors in Brazil has faced technical, behavioral, institutional and economic barriers.

Among these barriers are subsidized prices for certain classes of consumers - which discourage the rational use of energy - and the lack of information on ways to increase the efficiency of electricity use, even though the labeling program of the National Institute for Metrology, Standardization and Industrial Quality (Inmetro) and the PROCEL Seal have helped to reduce these barriers.

- **Expansion of knowledge and suggestions for energy conservation measures**

In commercial buildings or shopping malls, thermal accumulation systems can be economically feasible alternatives for reducing electricity consumption at those times when the tariff is higher. These systems allow the reduction of peak load by generating and storing heat at other times of the day. Architectural projects that make better use of natural lighting and ventilation are also options for reducing electricity consumption in new buildings. There are many opportunities to achieve energy savings in the industrial sector, particularly by increasing the efficiency of industrial processes, such as:

- Low-interest loans for electricity conservation programs and equipment replacement provided by government-owned financial institutions, such as, the Brazilian Social and Economic Development Bank (BNDES);
- Rebates for consumers who install new more efficient equipment, this can be financially advantageous for the concessionaires when the marginal expansion cost of the supply exceeds the cost of the rebate program;
- Creation of energy service companies, known as ESCOs, dedicated to auditing, installing new equipment and run conservation programs in other companies;
- Expansion and acceleration of the current program for minimum efficiency ratings for electrical appliances, as well as of the labeling programs;
- Creation, by the utilities, of incentives for residential consumers to replace inefficient air conditioners, refrigerators and freezers (concessionaires have lower discount rates than the final consumer, which can alter the feasibility of the investment in efficient appliances);
- Actions to increase the efficiency of public lighting in the services sector, such as replacing equipment (mainly lamps) and installing better designed lighting systems.

> Examination of the available literature indicates that the Brazilian power system has vulnerabilities to natural climate variability and to climate change, due to a tendency to lose renewable energy generating capacity, and in all regions.

- **Encourage new business models**

Reducing the vulnerability of the electricity generation system requires integration with other energy sources and undertakings on several scales. That is, another challenge to be considered is regarding the changes that occur in the electricity generation industry itself, both at the technological and economic levels.

Technical-economic paradigms have been strongly refuted, such as the large power stations, and new business opportunities have arisen in the installation and operation of small generating units. Small plants installed in streams and waterfalls, the use of biomass residues, wind farms in coastal regions and turbines driven by natural gas abound.

The economic impact was almost immediate: the new generation technologies, less dependent on economies of scale, opened the door to new producers, significantly improving the conditions of competition. In this scenario, the new players that stand out are local and regional companies and conglomerates, who entered the generation industry encouraged by the availability of smaller plants located near consumption centers that are built more quickly and in modules, with flexible operation, used only during peak hours. Nevertheless, consolidation actions must still be adopted, such as:

- Requirement that the utilities buy the surplus energy from sugar and alcohol plants at the avoided cost of generation, transmission and distribution, through long-term contracts;
- Incentives for interconnecting small generators to the public electricity grid;
- Important role for public financial institutions in creating financial solutions for projects in adaptation, vulnerability reduction and mechanisms for risk management and transfer for these new plants;
- Training of professionals in strategic positions to provide solutions in the areas of vulnerability reduction and adaptation;
- Designing tools to support strategic management by structuring baselines, assessing operational vulnerabilities and financing to create appropriate objectives for the customized management of their portfolios;
- Investment in induction policies, supporting the chain of sustainable business, which can face serious constraints, especially in relation to access to capital. These policies should offer investment products and not just funding;

- **Foster promotion of knowledge centered on vulnerability reduction in the electricity sector**

OAnother type of identified vulnerability was the scarcity of data and the lack of tools to assess the potential effects of climate change on the energy sector. Thus, EPE, ONS and ANEEL, under coordination of the Ministry of Mines and Energy (MME), must formalize a structure to address this issue and expand studies on the adverse effects of climate on the electricity sector and to propose appropriate actions, such as:

- Scientific research and education by public agencies, encouraging the development of scientific studies, recovery of historical data and training of teachers in the areas related to the study of climate changes and the natural variability of climate;
- New studies that examine the entire water balance in each basin, to increase the knowledge base on the relationship between the rainfall regime and river flows, which may alter as a result of deforestation, soil degradation or other land use changes that affect the physical characteristics of the river basin;
- Studies that consider the various factors capable of interfering in crops used in alcohol and biodiesel production. Among these factors are genetic innovations and irrigation techniques. Analyses of temperature and rainfall variation are also necessary for each stage of the production cycle as well as of the physical and chemical variations of soils;
- New studies that take into account the possibility that, given the actual effects of global climate change, other uses of water (such as irrigation, human and animal consumption, industrial consumption and even uses of the very energy sector that employs water, such as thermal power plants and oil refineries) may compete with hydropower generation;
- Incentives to research and development of breakthrough technologies, such as gasification of bagasse and combined cycle energy generation;
- Government initiatives to reduce barriers to information on newer technologies (such as the development of demonstration projects) and loans with attractive terms so that sugar and alcohol plants can adopt more efficient technologies;

- Studies to reduce the vulnerability of generation in the electricity system based on integrating energy sources and undertakings of differing scales;
- Strategies to encourage greater continental and regional integration among river basins and electricity systems; Ample and cost-free access to historical rainfall data produced by public agencies;
- Climate vulnerability maps for sub-basins, highlighting aspects related to hydropower generation and to the electricity system.

- **Reduce conflicts with other water and area users**

With regard to hydropower ventures, the expansion of demand for water resources - in both absolute values and diversity - will require a greater knowledge of the area where they are located, permanent monitoring of generating conditions –, and not just at the plant site and at the area surrounding the reservoir. Water balances should be more precise, collection of economic and environmental impact data must be more detailed. Finally, the tendency is an increase in the power plant's social responsibility towards the riverside community and other users. The challenge of hydropower generation is to integrate new issues into its planning and operation, and, therefore, new skills - often of a very different nature;

Besides optimizing hydropower generation, the diversified management of reservoirs reduces the negative impacts and expands the benefits for the basin and other users. This management stems from both the decision to install a power plant and the operationalization of the plant reservoir levels, and some social costs will eventually be internalized by the entrepreneurs because of government imposition, according to a trend observed at national and international levels. Therefore, investments in activities previously thought to be marginal will tend to increase, such as conservation of plant cover, regulation of the flow of rivers and their tributaries, control of effluent discharge, acquisition of hydrological data and management of land use in the river basin.

The issues raised in this section are presented in Frame 2.

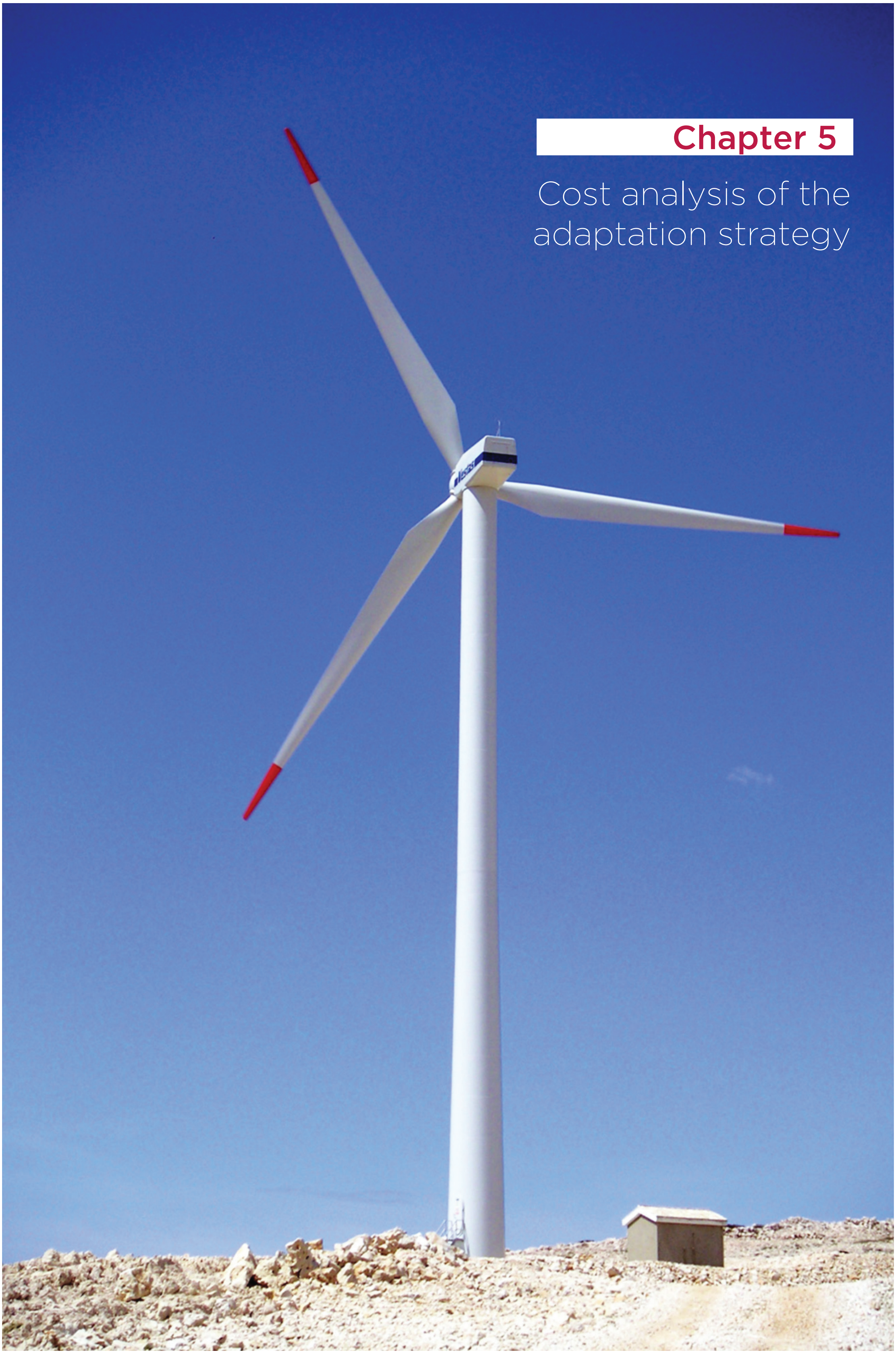
> Another type of identified vulnerability was the scarcity of data and the lack of tools to assess the potential effects of climate change on the energy sector.

Frame 2 - Classification of vulnerability and adaptation actions.

Actions	Time Frame	Attitude	Decision-making level
Encourage the rational use of energy	Short term	proactive	• Corporate Governance • Managerial
Promote greater energy efficiency in transmission and distribution	Short term	proactive	• Corporate Governance • Managerial • Operational
Reduce the direct dependence of hydropower generation on flows and ensure additional energy supply from other sources	Medium and long term	proactive	• Public Governance • Governança Corporativa
Expand the reliability of sector supply	Short and medium term	proactive	• Public Governance • Corporate Governance • Managerial • Operational
Encourage new business models	Short term	proactive	• Public Governance • Corporate Governance
Expand knowledge and suggestions for energy conservation measures	Short and medium term	proactive	• Academic Governance
Foster promotion of knowledge centered on vulnerability reduction in the electricity sector	Short and medium term	proactive	• Public Governance
Reduce conflicts with other water and area users	Short term	proactive	• Corporate Governance • Managerial • Operational • Participation of Civil Society

Chapter 5

Cost analysis of the adaptation strategy



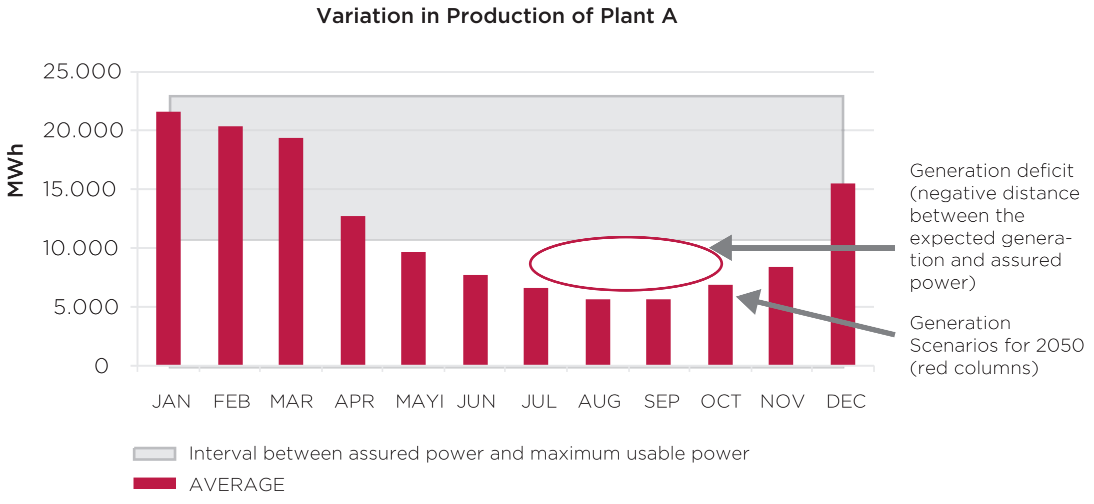
Based on the conclusions about the performance of the three plants analyzed in the previous stage from the perspective of climate variations, be they historical or due to climate change, we can analyze the additional supply of electricity from other sources to supplement the electricity generation scenarios drawn up for Plants A, B and C.

With the scenarios for electricity production variation prepared for 2020 and 2050 in mind, a cross-analysis of the deficit in meeting the assured power was carried out on the costs associated to each additional source. Elements used for this analysis were taken from the official data of the Energy Research Corporation (EPE) found in the 2030 *National Energy Plan*, published in 2008.

5.1 Generation deficit in meeting the assured power

To determine the generation deficit for each case study plant, it was presumed that whenever a plant was generating less than its assured power, the plant owner must provide the non-generated percentage to the system every month.

For 2020, the generation scenario was taken to be the monthly generation averages based on the monthly flow averages from 1931 to 2010, as shown in Figure 37 for Plant A:



Generation deficit (negative distance between the expected generation and assured power)

Generation Scenarios for 2050 (red columns)

Figure 37 - Monthly generation averages based on monthly flow averages from 1931 to 2010.

Source: Own elaboration.

For 2050, both moderate and extreme scenarios were considered for the generation scenario and the same method was used, examining the deficit between the expected generation in each scenario and the assured power for the period, as shown by the example for Plant A below (Figure 38).

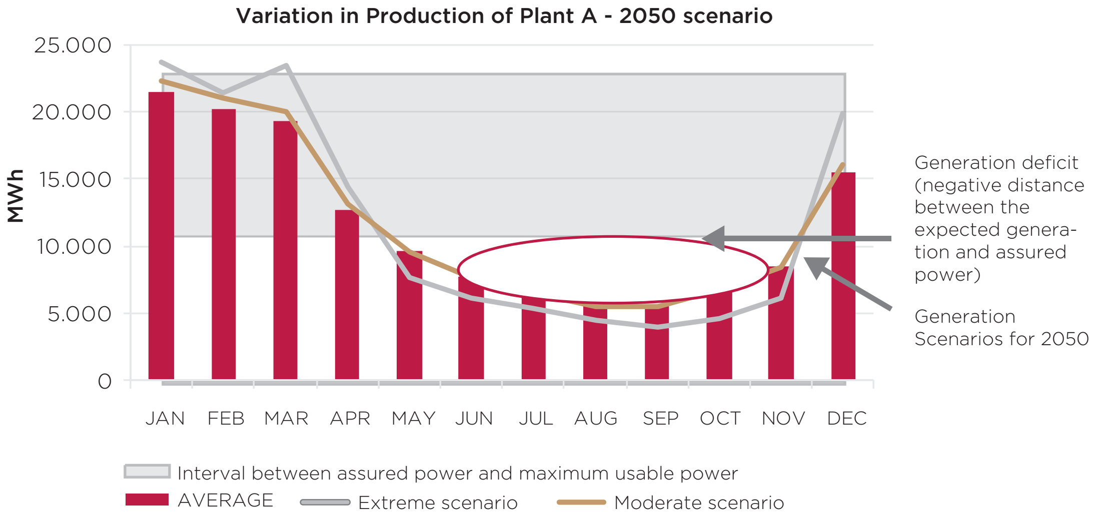


Figure 38 - Energy generation scenarios for 2050.
Source: Own elaboration.

5.2 Selection of additional energy sources

The additional energy sources considered for analysis were chosen from the main sources used in the domestic supply of electricity in Brazil in 2009, as published by EPE in the 2011 *National Energy Balance*, i.e.: wind, hydro, biomass thermal, gas thermal, coal thermal, oil thermal and nuclear. Photovoltaic energy will be considered further on, in the qualitative analysis of renewable sources, since the costs related to this source have not yet been consolidated by EPE.

5.3 Comparative analysis of electricity generation costs per additional source

To carry out the comparative analysis of the costs of the additional electricity generation, the following data sources published by the Federal Government were chosen as possible premises: (1) average tariff of electricity sold in auctions from 2005 to 2011, updated to 2012 values by the Ministry of Mines and Energy and the electricity tariff of the National Interconnected System (SIN); and (2) the cost of production and investment used to estimate the equilibrium rate per source, calculated by the EPE in the 2030 *National Energy Plan* (BRASIL, 2007).

1. The price of electricity in auctions is directly affected by the domestic regulatory framework and by the fiscal incentives provided by ANEEL. Although values are updated, we concluded that this premise is not suitable for the comparative cost analysis for 2020 and 2050, since it would project the current regulatory framework to the future, an affirmation that cannot be presumed by this study. We also believe that the SIN electricity rate could be used for comparative purposes only if it were presented together with the selling price of energy in auctions, since it is equally affected by the regulatory framework and reflects the electricity selling price, incorporating subsidies and taxes.
2. The cost of production and the investment per energy source used in the 2030 National Energy Plan (BRASIL, 2007) were calculated by EPE from values observed in 2006 and 2007, leading to a data discrepancy. Indexation of the amounts used by EPE was initially considered, but later discarded as it wasn't capable of reflecting technological and market changes that these technologies underwent over the past five years. Since the objective of the analysis is to provide a comparative analysis for 2020 and for 2050, we believe that the use of figures published in 2007 will not significantly affect the quality of the analysis, except for the comparative reduction of wind generation costs in the last few years. The comparative reduction experienced by the wind technology was due to economies of scale that may also be seen in some of the other considered sources in the next few decades.

Thus, alternative (2) was chosen, without indexation, to supply the comparative financial assessment of the additional electricity sources (Table 5).

Table 5 - Investments, production costs and equilibrium tariff for several energy sources.

Source	Investment (USD/kW)	Production cost (R$/MWh)	Equilibrium tariff (R$/MWh)
Wind	1,300	169.40	256.50
Hydro	1,200	68.80	114.40
Biomass thermal	1,100	83.16	122.39
Coal thermal	1,400	172.92	217.12
Natural-gas thermal	400	127.48	152.17
Oil thermal	1,000	119.10	164.90
Nuclear thermal	1,800	147.26	196.97

Source: BRASIL, 2007.

The equilibrium tariff corresponds to the production cost plus the sectoral charges related to transmission and distribution and taxes. Since the idea is to assess the cost of vulnerability reduction and adaptation for each of the plants, the production cost was believed to be the most suitable for the purposes of this study, since it doesn't include the discussion on trends for electrical energy transmission and distribution.

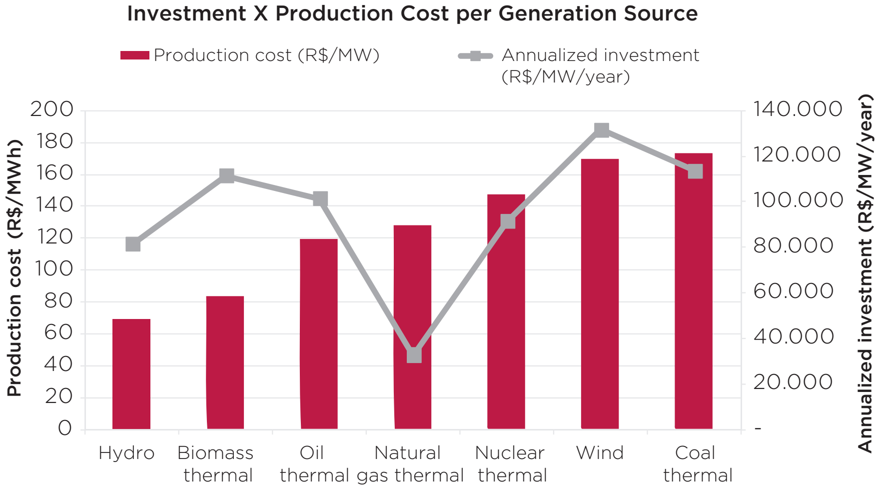


Figure 39 - Investment x Production Cost per generating source.
Source: Own elaboration.

When the investment required to implement electricity generating plants per year of useful life is compared to their respective production cost for each type of technology (Figure 39), it is possible to see that despite having an average production cost when compared to other sources, the thermal power plants using natural gas correspond to the lowest investment per installed MW. On the other hand, hydropower, with the smallest production cost, when viewed from the perspective of investment makes all other renewable sources competitive, such as, biomass. Wind energy has the largest investment requirements and the second highest production cost. Coal-fired thermal power plants, in addition to representing the highest production cost, are responsible for the second largest investment requirements. In this comparison, nuclear energy has the third highest production cost and is fourth in investment requirements. The largest discrepancy between production cost and investment is found between natural gas-fired and biomass-fueled thermal plants, which exhibit inverse performances. Hydropower, on the other hand, represents the most competitive alternative, as it has the lowest production cost and the second smallest investment requirement.

5.4 Comparative analysis of energy cost per plant for the 2050 scenarios

The comparative cost analysis took into account the sum of the monthly electricity generation deficits multiplied by the production cost per source for each plant plus the annualized investment requirement for its useful life for each energy generating technology.

A premise only used for the purposes of this analysis was that the plant-owner or investor must replenish the National Interconnected System, or their own activity, to cover the deficits in those months where generation falls below the assured power and, thus, the costs related to this replenishment were calculated for each source.

For Plant A, the accumulated generation deficit was estimated at 25 GWh in 2050 for the moderate scenario and at 37 GWh for the extreme scenario, resulting in the following adaptation costs (Figure 40):

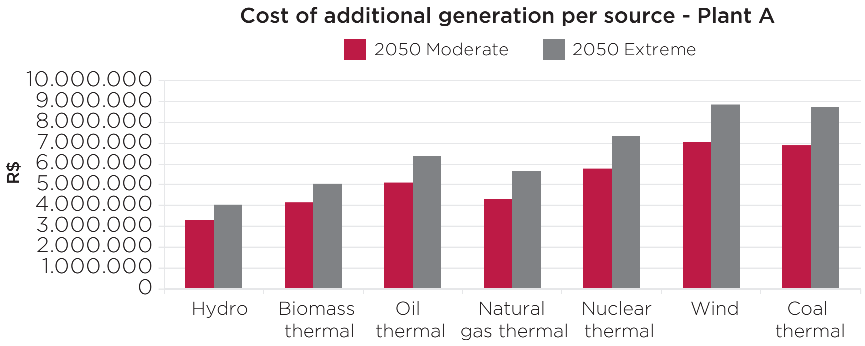


Figure 40 - Cost of additional generation per source - Plant A.
Source: Own elaboration.

For Plant B, the accumulated generation deficit was estimated at 7 GWh in 2050 for the moderate scenario and at 9 GWh for the extreme scenario, resulting in the following adaptation costs (Figure 41):

> Since the idea is to assess the cost of vulnerability reduction and adaptation for each of the plants, the production cost was believed to be the most suitable for the purposes of this study.

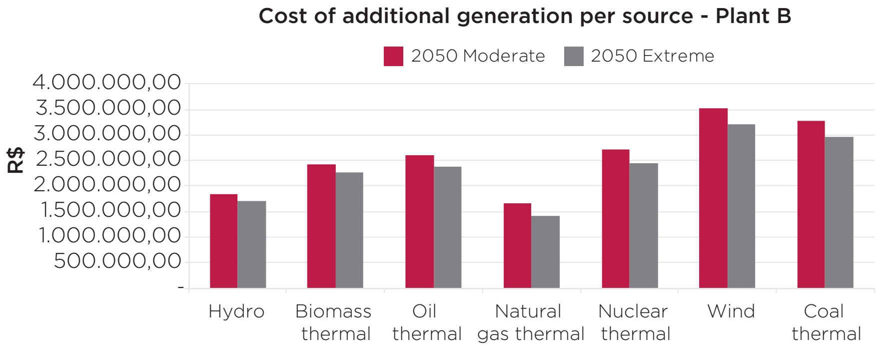


Figure 41 - Cost of additional generation per source - Plant B.
Source: Own elaboration.

For Plant C, the accumulated generation deficit was estimated at 2,400 GWh in 2050 for the moderate scenario and at 3,400 GWh for the extreme scenario, resulting in the following adaptation costs (Figure 42):

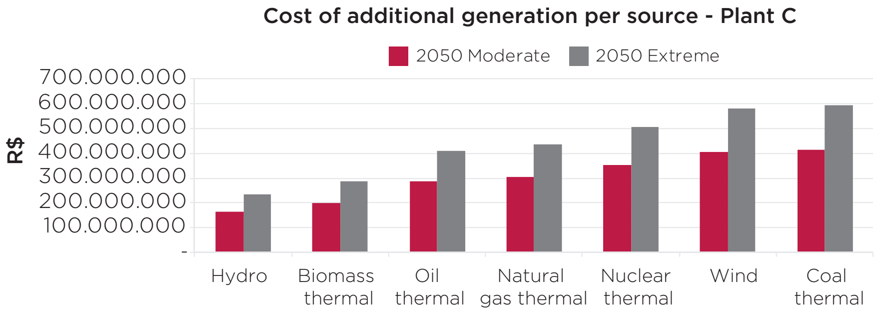
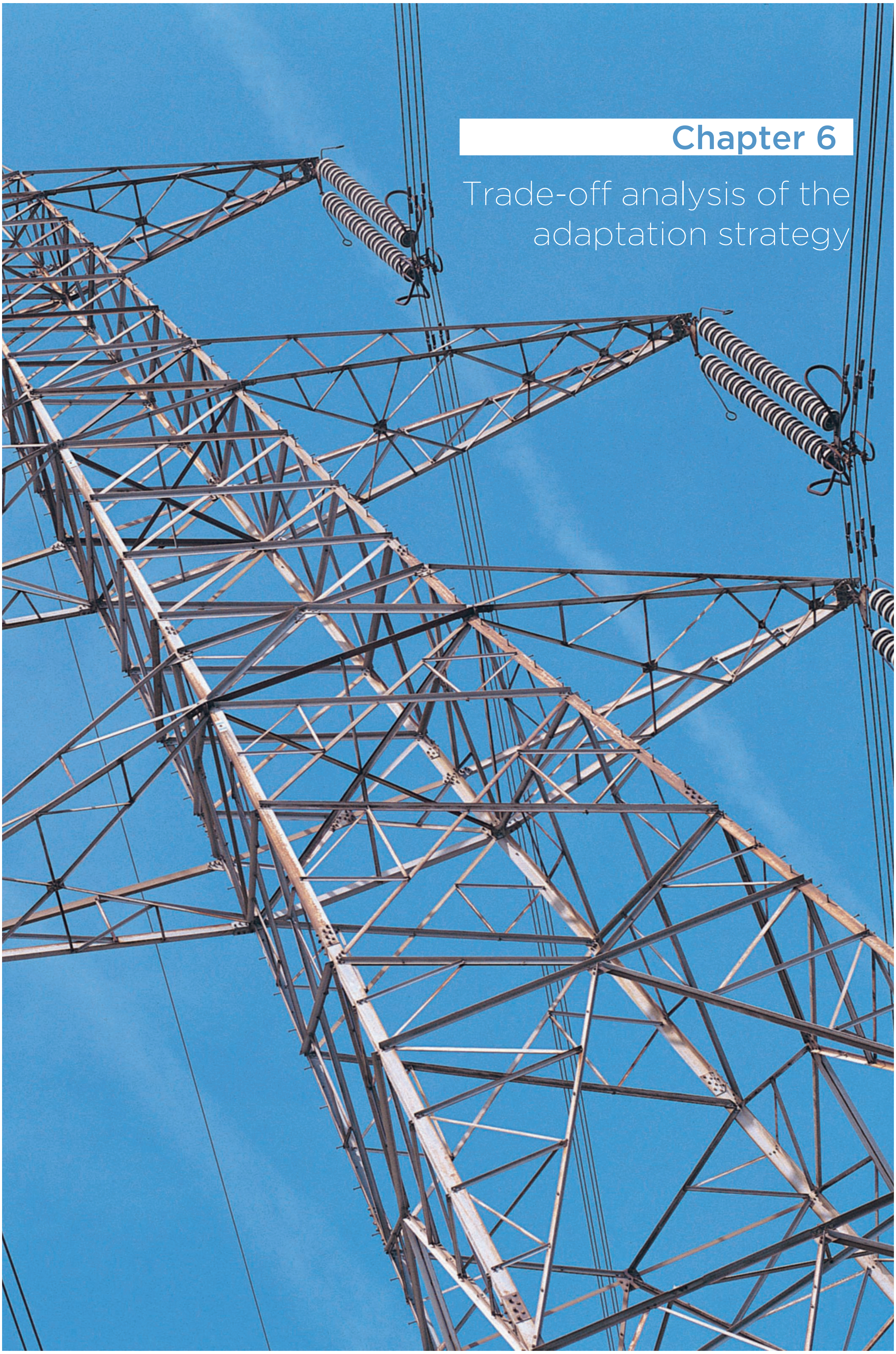


Figure 42- Cost of additional generation per source - Plant C.
Source: Own elaboration.

As seen in the above graphs, to meet generation requirements, the coal-fired thermal plant and wind energy proved to be the alternatives with the highest cost, while providing additional energy from another hydropower is the option with the lowest cost. Since this paper is analyzing the vulnerability of hydropower itself, it is recommended that if the owner opts for the cheapest option, he also should analyze the physical conditions of the additional hydropower plant and examine if the basin where it is located has a hydrological behavior similar to that of the plant under study.

Oil-fired thermal power plants can be considered intermediate alternatives (not taking into account those of lowest and highest cost). The biomass-fueled thermals and gas-driven thermals are the best option after hydropower. The trade-off among them depends both on the size of the plant and the monthly distribution of the deficit.



Chapter 6

Trade-off analysis of the adaptation strategy

In order to contextualize some of the alternatives examined by this analysis, some information related to the Brazilian regulatory framework, even though it may undergo significant changes by 2050, are highlighted here.

Over the past few years, the Brazilian Government has encouraged the generation of renewable energy through public policies, financial incentives, public financing and regulatory policies. Frame 3 lists the incentives established during the process of investing USD 70 billion from 2006 to 2011.

Frame 3 - Main policies to encourage renewable energies.

Area of Action	Policies
Energy Market	Feed-in tariffs, auctions, mandatory fuel mix, ban on harvesting sugar cane with fire in the state of São Paulo and the requirement for storage of anhydrous ethanol in Brazil.
Equity financing	Infrastructure funds
Debt financing	Financing, e.g., BNDES Finem
Taxation	Fiscal benefits, import duties and fiscal reduction

Source: (BLOOMBERG, 2012)

- ### Auctions with tariff incentives for renewables

After the reform of the Brazilian electricity sector in 2004, electricity contracts came to be acquired through auction, whose objective is to ensure electricity supply to the market regulated by the lowest-price criterion. Auctions for alternative sources and for reserves have been promoted to increase the share of SHPs, biomass-fueled thermal plants and wind farms in the country's energy mix. Auctions exclusively for alternative renewable sources were established because they usually have a higher cost, thus less competitive, in comparison to traditional energy sources.

The reserve auctions aim to contract energy in addition to that required to meet the demand of distributors, that is, their main objective is to ensure the security of electricity supply to the system through generation plants contracted specifically for this purpose.

- ### Fiscal exemption

According to Law No. 9,427/1996, altered by Law 11,488/2007, for hydropower facilities with capacity smaller than or equal to 1 MW (MHPs) and for those using solar, wind, biomass and qualified co-generation whose power provides to transmission or distribution systems less than or equal to 30 MW, ANEEL determines that a reduction percentage of not less than 50 % is to be applied to the tariffs for the use of electricity transmission (TUST) and distribution (TUSD) systems, incident on the production and consumption of the energy commercialized by the undertakings.

Furthermore, a bill is currently underway in the Senate, PLS 311/2009, to establish the Special Taxation Regime for Incentives to the Development and Production of Alternative Electricity Sources (REINFA) and provides for measures to encourage production and consumption of clean energy (BRASIL, 2012). Among the beneficiaries of REINFA are those that:

I Undertake research, development and production of equipment used in the generation of wind, solar and tidal energy, as well as of new technologies or materials for storing energy;

II Generate electricity in small hydropower plants or in wind, solar, tidal plants and in thermal plants that use biogas from agricultural products, garbage and sanitary landfills;

III Produce vehicles powered by electric motors, hybrid or otherwise.

Those that satisfy REINFA requirements will be exempted from the PIS/PASEP and COFINS taxes on their gross revenue and from the PIS/PASEP-Import, COFINS-Import and other import duties on the goods that do not have a locally produced equivalent and the services required for their activities when directly imported by the REINFA beneficiary. It must be stressed that the bill is being currently examined in the Senate and is not yet in effect (SENADO, 2012).

Another fiscal incentive for renewable sources used in electricity generation is described in the ICMS Agreement No. 101/97, which awards ICMS exemption in operations with the equipment and components specified in the agreement for the use of solar and wind energy. Laws No. 7,990/1989 and 9,648/1998 exempt hydropower plants with capacity lower than or equal to 30 MW (that is, MHPs and SHPs) from paying the Financial Compensation for Using Water Resources (CFURH), which corresponds to 6.75 % of the total amount of the produced electricity (the current reference tariff is used in this calculation). Furthermore, Law No. 10,438/2002 exempts companies that generate energy exclusively from wind, solar and biomass facilities as well as SHPs and qualified co-generation, to annually invest the amount of at least 1 % of their net operational revenue in R&D in the electricity sector.

> Over the past few years, the Brazilian Government has encouraged the generation of renewable energy through public policies, financial incentives, public financing and regulatory policies.

• New regulations for photovoltaic solar energy

In Brazil, photovoltaic solar electricity generation is not yet competitive, with far higher tariffs than other established sources. However, in 2012, the government undertook efforts to establish regulations to promote the consolidation of this technology in Brazil more competitively. Among these actions, ANEEL published Normative Resolution No. 481/2012, which introduced, for solar sources with an installed capacity less than or equal to 30 MW, an 80 % reduction in the tariffs for use of the electrical transmission (TUST) and distribution (TUSD) systems for ventures that begin commercial operation by 31/Dec/2017, applicable during the first 10 years of plant operation; thereafter, the reduction will go down to 50 %.

• Impact of possible new policies to reduce greenhouse gas emissions

In response to the increased awareness of individuals and the public sector, as well as its international commitments, the government has been seeking mechanisms to reduce greenhouse gas emissions in line with the National Climate Change Policy. In 2009, the Federal Government committed to voluntarily reduce emissions by 36.1 % to 38.9 % by 2020.

Since 2009 state governments in Brazil have begun to establish actions, policies and laws to mitigate greenhouse gas emissions in their territories. If these policies are implemented, there will be an increased stimulus to the development of clean technologies, which includes renewable energy. However, if sectors are not prepared to receive the new regulations, they will have to bear additional costs of adapting to new requirements, which may significantly affect the competitiveness among market players.

6.1 Economic assessment

As seen in the analysis of the above section, when viewed only from the perspective of the financial cost, fossil and renewable sources perform at the same level, where hydropower stands out as the cheapest. The prospect of climate change, however, requires assessment of the contribution of each of these sources to global warming and, therefore, incorporation of additional costs, as yet not projected, giving decision makers a broader framework to be considered in their medium and long-term planning.

To evaluate the contribution of each generation source to global warming, the emission factors for CO_2e were used, as defined by EPE in the 2030 National Energy Plan. For the purposes of this study, only the emissions of CO_2e associated to the operation of each generating technology was used, in order to maintain comparability with the criterion used in the selection of production cost.

As this study is applied to the Brazilian reality, where generation is mainly based on agro-industrial residues (e.g., sugar cane bagasse), the operating emissions of the biomass-fueled thermal plants were considered to be neutral (Figures 43, 44 and 45).

> "It must be stressed that the need to reduce global greenhouse gas emissions contributed to a greater use of nuclear energy in several countries, particularly those with fewer natural resources, and to the development of other energy sources."
>
> Source: BRASIL, 2007.

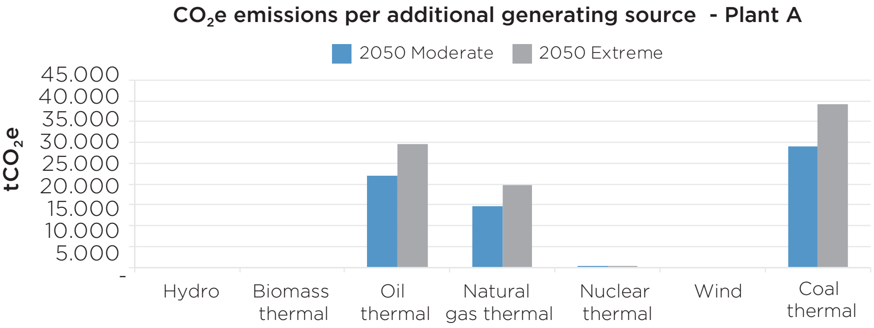


Figure 43 - CO_2e emissions per additional generating source - Plant A.
Source: Own elaboration.

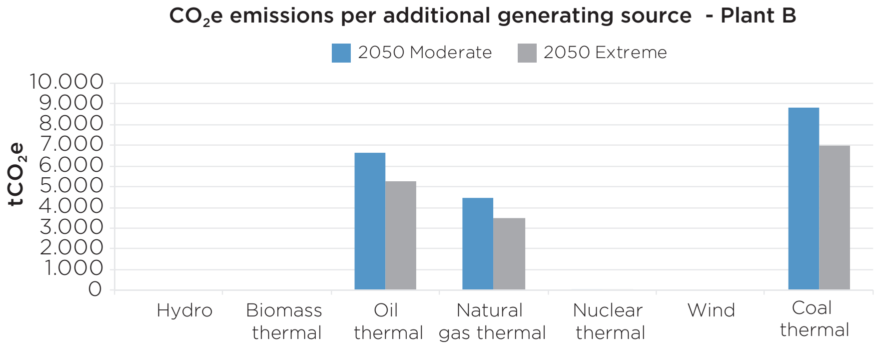


Figure 44 - CO_2e emissions per additional generating source - Plant B.
Source: Own elaboration.

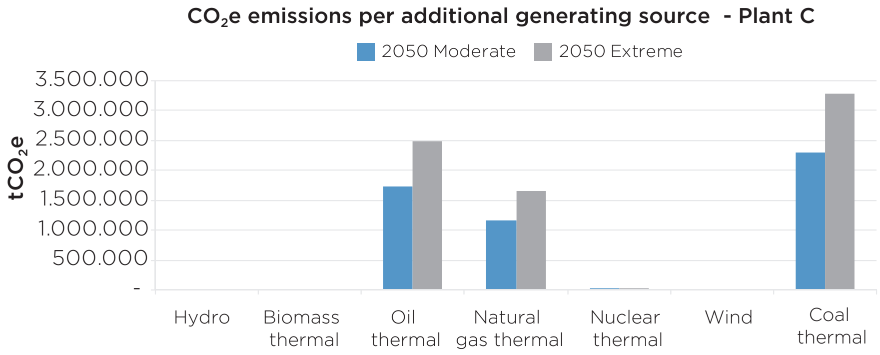


Figure 45 - CO_2e emissions per additional generating source - Plant C.
Source: Own elaboration.

In all of the additional generation scenarios, the coal-fired thermal plants have the highest level of CO_2e emissions, followed by oil and natural gas-fired thermal plants.

Despite the high comparative levels of the contribution to global warming, fossil fuels represent a significant advantage for energy security over renewable sources, when considering exposure to extreme weather events. Energy planning for investors or plant-owners involves a trade-off between the cost of electricity and its potential contribution to global warming. Adopting as premise a possible restriction of GHG emissions from electricity generation in 2050, together with pricing of this impact, it is possible to simulate the additional cost of fossil sources with respect to their warming potential.

To compose the simulation of the financial impact of possible pricing of emissions, two scenarios were selected.

The first (1), considers higher values, such as those prices currently practiced in New Zealand and Australia. The second scenario (2), presumes that any pricing of GHG emissions to be established in Brazil will be at lower levels, similar to the current carbon market prices for transferring emission reductions in developing countries to industrialized countries. To estimate these scenarios, data from the following sources were selected:

a) Scenario 1: USD 25 / tCO_2e – amount used as reference by the IEA[6] to establish the emissions reductions scenarios related to energy for 2050, cited by Nicholas Stern in Chapter 9 of his study "The Economics of Climate Change".

b) Scenario 2: EUR 2.85 / tCO_2e – price of certified emissions reductions (CER) in the market regulated by the United Nations (UNFCCC) in 09/08/2012.

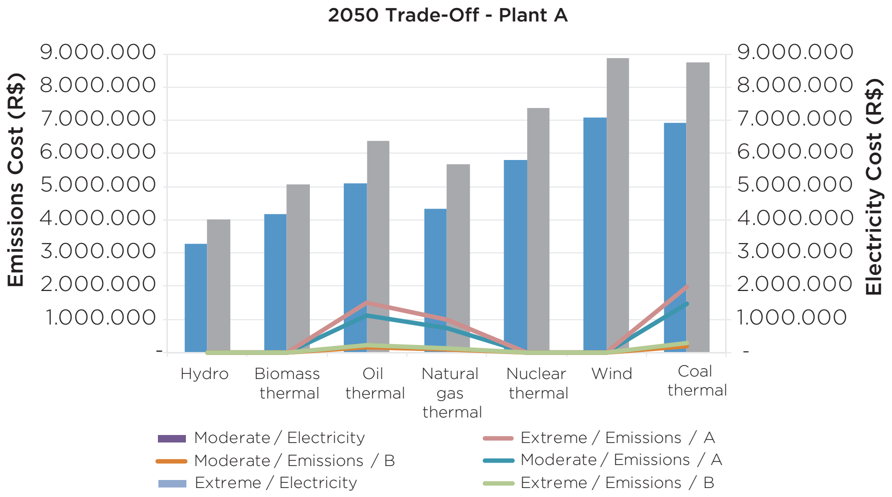


Figure 46 - Trade-Off 2050 - Plant A.
Source: Own elaboration.

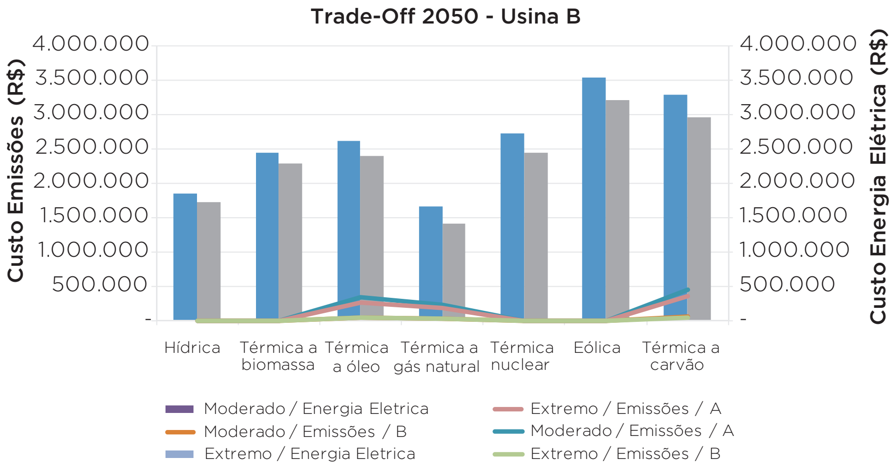


Figure 47 - Trade-Off 2050 - Plant B.
Source: Own elaboration.

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[6] IEA - International Energy Agency

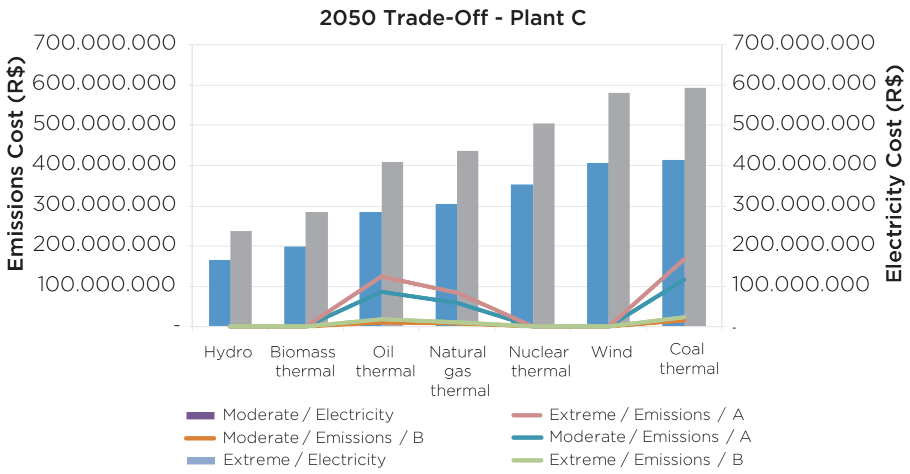

Figura 48 - Trade-Off 2050 - Usina C

Fonte: elaboração própria.

(a) Figures 46, 47 and 48 show that for both moderate and extreme climate alterations for 2050, the possible costs associated to scenario 1 of the value of GHG emissions are seen as significant factors in the choice of electricity energy generation technology. The higher the possible costs of GHG emissions, greater will be the difference of the alternatives using coal, oil and natural gas in comparison to renewables and nuclear energy.

(b) But in scenario 2, the possible emission costs tend to contribute to the displacement of hydropower and biomass technologies to a cost level lower than the others and for alternatives such as wind energy to become feasible, thus being better placed as to the final energy cost. In this scenario, other decisive factors, such as energy security and exposure to climate events, will be even more relevant in decision making.

6.2 Qualitative assessment

In addition to the items specified in the economic analysis, some qualitative properties related to the Brazilian electricity market warrant attention in this study. On the one hand there are financial incentives and the possible payment for environmental services, which provide instruments for market self-regulation to adapt to the energy generation scenarios described by this study and that influence investment trends in the field of electrical energy. On the other hand, from a technological perspective, technologies for adaptation, increased competitiveness of renewables and the future of fossil sources must also be considered.

Cultivating Good Water Program

Itaipu Binational, which encompasses more than 28 municipalities, fosters good agricultural practices in the rural areas to diminish the impact of agricultural production on the reservoir waters, particularly from erosion. Payment to farmers is effected through cost-free technical assistance, a means of encouraging environmental preservation.

(ITAIPU, 2012)

6.2.1 Financial aspect

- **Payment for environmental services**

According to the Food and Agriculture Organization (FAO), Payment for Environmental Services (PES) is a flexible compensation mechanism by which providers of environmental services are paid by the users of these services. Services are related to the products obtained from the ecosystem, the benefits obtained from the regulation of the ecosystem and the immaterial benefits of the ecosystem, such as ecotourism.

From the perspective of hydropower generators, PES turns out to be a business opportunity to solve problems related to the degradation of rivers, caused by various sources of pollution and deforestation. In particular, the degradation of riparian forests leads to silting/sedimentation in rivers, smaller springs and increased flooding. It is important to emphasize the need to conserve water springs, which are essential for the hydrological function of the basin, increasing the uniformity of the flow peaks, which directly impact on the hydropower maintenance costs. Therefore, the weather events related to river degradation may cause additional costs due to the need for dredging the hydropower lakes, as well to operational problems in the dams, affecting the availability of water in the region and impairing supply.

- **Financial incentives**

According to the *Bloomberg New Energy Finance* report, BNDES is the main Brazilian financing agent, responsible for about USD 4.9 billion of the USD 7.9 billion of total domestic investments in 2011. This is due to the major participation of the Bank in the government's development projects, such as the Program to Accelerate Growth (PAC), as well as infrastructure projects. From 2003 to 2010, the institution financed about USD 2.8 billion in SHPs, USD 13.5 billion in other hydropower plants, USD 1.2 billion in biomass and USD 0.9 billion in wind energy.

The Bank offers financing through various credit lines for projects that enable implementation, expansion and modernization and acquisition of new equipment, through financing mechanisms specially geared to encourage renewable energy, such as:

> The prospect of climate change, however, requires assessment of the contribution of each of these sources to global warming and, therefore, incorporation of additional costs, as yet not projected, giving decision makers a broader framework to be considered in their medium and long-term planning.

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[7] Bloomberg New Energy Finance. http://bnef.com

Frame 4 - Credit lines

Credit lines	
BNDES Finem	
Support for energy efficiency projects - PROESCO	Special conditions for environmental projects that promote sustainable development
Alternative energies	For projects that contribute to energy efficiency
Programs	
Climate Fund	Support for projects or studies and financing of ventures that aim to mitigate the effects of climate change, such as renewable energy and efficient transport projects
PRONAF Eco	Support for family farmers, through investment in renewable energy and environmental sustainability technologies.
Investment Funds	
BNDES Innovation in Environment Fund	Support for entrepreneurship and development of investment opportunities in innovative companies, in order to foster the development of clean technologies
Brasil Sustentabilidade Investment Fund (FIP)	Focus on Clean Development Mechanism (CDM) projects with potential to generate Certified Emission Reductions (CERs)
Caixa Ambiental Investment Fund (FIP)	Focus on sanitation, solid waste treatment, clean energy generation and biodiesel

Source: (BNDES, 2012)

In the case of the Federal Government, one of the foremost programs for encouraging renewables is the Program to Encourage Alternative Sources of Energy - PROINFA. The program was created to increase the share of renewable sources in the Brazilian energy mix, specifically, the share of wind and biomass and small hydro plants in the National Interconnected System, but, today PROINFA is no longer accepting new ventures. In the case of SHPs, the most important program today is the Program to Develop and Commercialize Electricity from Small Hydropower Plants (PCH-COM), developed by the MME in partnership with Eletrobrás and BNDES. The Bank provides financing for the construction of SHPs and Eletrobrás guarantees the purchase of energy from the plants through long-term contracts, allowing entrepreneurs access to BNDES financing.

The lines for development of renewable energies are important because they can make the additional energy from low carbon-intensive sources more competitive, consequently contributing to climate change mitigation.

Bearing in mind the 2020 and 2050 time frames and that scientific studies indicate that we are still in a scenario of a temperature increase greater than 2 oC (IPCC scenario A2)[8], the trend towards a greater availability of these lines becomes likely, since mitigating measures can be substantially strengthened, which may generate an increasingly favorable environment for investment in renewable sources.

Investment trends

In the first decade of the 21st Century, investments in renewable energy sources left a scenario of *ad hoc* applications to become an industry that currently contributes to an estimated additional 60 GW per year in the world. This rapid growth has drawn the attention of scientists, investors and policymakers. Countries have adopted domestic policies that encourage investment and increase equipment production and competitive-

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[8] IPCC - Intergovernmental Panel on Climate Change.

ness. Increasing scale has also contributed to reducing deployment and even operational costs.

In 2011 alone, global investments in renewable energy grew 17 % compared to the previous year (Figure 49).[9]

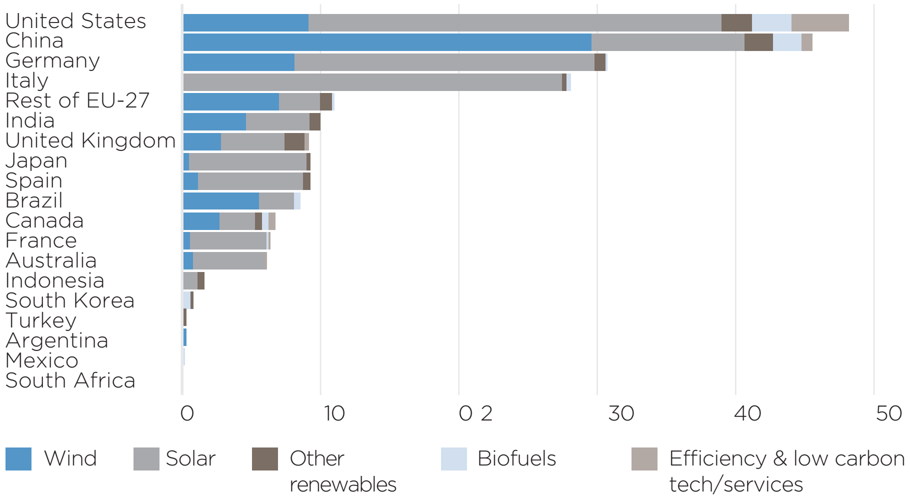

Figure 49 - Investments per country and sector, 2011 (USD billion).
Source: REICHERT *et al*., 2012.

In a global comparison, in 2011, the United States was the largest investor in renewable energy, followed by China. Investment in clean energy tends to decrease in Europe in 2012, due to the poor economic situation, while in countries such as China, Indonesia and Australia it will increase due to the growing energy demand and to a less unfavorable macroeconomic scenario in relation to Europe.

An interesting element is that the wind energy sector, which had been receiving the most investments during the past few years, has been overtaken by photovoltaic energy sector (in terms of invested dollars and not installed gigawatts). This trend, if confirmed, could lead to a significant increase of the competitiveness of solar energy in comparison to other energy sources, which expands the range of renewable options to the prejudice of fossil energy. In the context of this study, this is an important fact, since photovoltaic energy is less exposed to the analyzed risks than most of the sources widely used today in the Brazilian energy mix. But, this source does not yet offer the same level of security to the supply that the other sources do, because of low storage capacity of the energy generated by photovoltaic panels.

6.2.2 Technological aspect

- **Adaptation technologies**

The adoption of new technologies is essential to reduce the vulnerability and increase the capacity for adaptation of hydro-

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[9] REN 21, 2012 *Renewables 2012 GLOBAL STATUS REPORT*. (Paris: REN21 Secretariat)

power plants. Although each type of plant - HPP, SHP and MHP - has different generating characteristics, the factor which has the greatest influence on the capacity to adapt to climate variability is exposure of each plant to flow conditions. Plants that have reservoirs tend to be more resilient to climate variability and climate change due to their water storage capacity, since it leads to smaller oscillations in the flow of water that passes through the turbines.

The adoption of technologies that allow increases in the adaptive capacity of already installed run-of-river plants are limited for several reasons, including: 1) inability to manage flow because of the lack of infrastructure for storage; 2) greater difficulty in substituting more efficient turbines; 3) energy efficiency gains in cross-flow turbines will be more difficult.

According to a World Bank study (ESMAP, 2011) regardless of the characteristics of the plants, large investments must be made in R&D to develop new technologies and improve current equipment to be able to reduce vulnerability and increase the adaptive capacity of these power plants. It is further recommended that the pattern of rainfall and flow of the rivers of the basins where the plants are located be monitored, in order to better plan plant operations and equipment maintenance.

The Bank also mentions the following measures to increase the adaptive capacity of the plants (Frame 5):

Frame 5 - Measures for vulnerability reduction and adaptation

Measures for vulnerability reduction and adaptation	Type of plant
Build silt control gates	With reservoir
Increase the height of reservoirs	With reservoir
Build small reservoirs in upper basins	With reservoir
Adapt operations to the capacity and the flow regime	With reservoir and run-of-river
Change water reserves and reservoir management	With reservoir
Regional integration through transmission connections	With reservoir and run-of-river
Energy storage technologies	With reservoir and run-of-river
Increase the capacity to discharge extra volumes of water	With reservoir
Change in the number and types of turbines	With reservoir and run-of-river
Modify the dimensions of the channels to reduce heat losses and increase the discharge capacity	With reservoir and run-of-river
Modify the characteristics of the electrical components	With reservoir and run-of-river
Improve the efficiency and design of equipment	With reservoir and run-of-river
Instruments for monitoring climate variations and river behavior	With reservoir and run-of-river

Source: (ESMAP, 2011)

According to Harrison (2005), the most effective option for run-of-river plants is to vary the type of turbine according to the variation of the river flow where it is located and to the energy demand throughout the year. To do so, a careful analysis of the physical and market conditions of the location of the plant is recommended. In using turbines with a greater generating capacity during the months of greater flow, the turbine will allow greater hydroelectric generation. On the other hand, in the drought months, the flow is smaller and the turbine's generating capacity is substantially reduced, since its parameters for using the flow are intended for greater generation. This leads the plant to generate less, because there is no way to generate all the possible energy with the little amount of water flowing through it. It is therefore necessary to analyze the seasonality of the flow of the river where the plant is located. Another important factor is the seasonality of the energy demand. In the cases where the energy demand is greater in periods of high river flow, the expense of installing a higher capacity turbine is worthwhile, even if there is a somewhat larger loss during the drought periods. In the case of this study, for example, these elements should be taken into account at the time of defining the type of turbine technology to be used if the option of deploying a run-of-river plant were adopted to meet the energy generation gap of the analyzed plants.

• Increased competitiveness of renewable sources

The development of leveled global electricity costs shows a downward trend in the costs of generation from renewable sources. The analysis below is based on a qualitative evaluation of the following generation technologies: Wind, solar photovoltaic, biomass, coal, natural gas, oil and nuclear-driven thermal power plants and hydropowers.

According to the *Bloomberg New Energy Finance* report, 2011 saw significant reductions in the cost of generation of a wind MWh (9 % decrease). From 2009 to 2011, according to the same report, the prices of wind turbines suffered a significant drop (25 %). The main reasons for this price reduction are technological improvements followed by economies of scale which lead to cost reduction and ensuing production increase, in addition to a glut of turbines in the market because of the fall in demand caused by the financial crisis.

Given current trends, the costs of wind energy are expected to become competitive with gas turbine generation by 2016. Currently, only wind energy projects with the most efficient turbines that are located in areas with higher wind speeds are competitive. Photovoltaic solar generation also showed significant cost reductions. The crystalline silicon technology experienced a 35 % drop in price and thin-film, 31 %. This reduction in cost of solar can be explained by the increasing competition in the photovoltaic panel supply chain, mainly from China.

The costs of generation from fossil sources covered in this study (natural gas, coal and oil), as well as nuclear energy generation, had small variations in generating costs during the same period. For biomass-fueled thermal power plants a drop of 2 % was observed during this period. For hydropower generation technologies, changes in costs were not observed, probably because these technologies are already established, with quite competitive costs.

> Investment in clean energy tends to decrease in Europe in 2012, due to the poor economic situation, while in countries such as China, Indonesia and Australia it will increase due to the growing energy demand and to a less unfavorable macroeconomic scenario in relation to Europe.

• Future of fossil sources

Energy generation using fossil sources suffers constant criticism due to the uncertainty of their future availability and their environmental impacts, particularly those associated to the increase of greenhouse gas emissions. However, in terms of energy security, this type of electricity generation still has an important role. Fossil fuels - coal, natural gas and oil - given their high capacity for power generation (high calorific value) and greater control of their availability, even if this availability has a finite nature, are a fast and efficient solution for generating electricity in scenarios of extreme events and climate change.

According to EPE, the composition of primary energy fossil sources in the Brazilian energy mix (2010) was 53 %.[10] This occurs for many reasons, from fossil fuel subsidies to access to reserves of energy sources. Natural gas has a smaller share in this mix and, for this reason, Petrobras intends to invest from 2010 to 2030, an amount of 50 to 55 billion reals in natural gas exploration and production and subsequent processing and transport at high

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[10] Oil and byproducts, coal and byproducts and natural gas

pressure. The high energy potential of natural gas has a significant environmental advantage over other fossil fuels: the large reduction in CO_2 emissions - about 20 to 25 % fewer than fuel oil and 40 to 50 % fewer than solid fuels such as coal.

In the case of coal, even though Brazil has large reserves and its exploitation is attractive - one fifth of the investment cost of natural gas and one quarter of oil extraction - the Brazilian coal has a high level of impurity and low calorific value when compared to the international standard. According to PNE 2030, investments of about USD 330 billion dollars will be required for exploration and production of resources discovered in the pre-salt layer. Another event responsible for the largest investments in the sector was the blackout in 2001, which required the operation of thermal power plants to cover the energy deficit caused by the low production of hydropower plants.

Thus, from the perspective of the country's energy security, the fossil-fuel driven thermal power plants are an alternative that must be considered to ensure the coverage of deficits in hydropower generation, as simulated in this study. This analysis should take into account future scenarios that affect the decision to expand fossil source generation, such as, an upwards trend in the price of the oil barrel, pointed out in IEA studies (Figure 50).

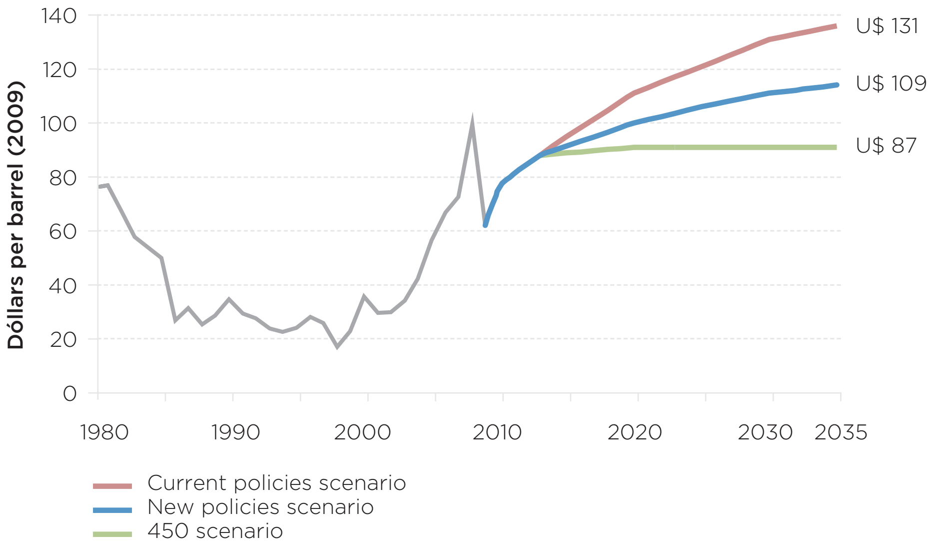

Figure 50 - Evolution of oil prices in the WEO scenarios.[4]
Source: OECD/IEA, 2010.

Brazil's exposure to these price oscillations may be crucial, given the high volume of these imports. Brazilian imports increased by 275 % for natural gas, 111 % for coal, 137 % for diesel oil and by 1,283 % for fuel oil, from 2010 to 2011 (BEN, 2011). Figure 51, taken from the 2010 *National Energy Balance* (BEN), shows the dependence of the Brazilian energy sector.

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[11] World Economic Outlook

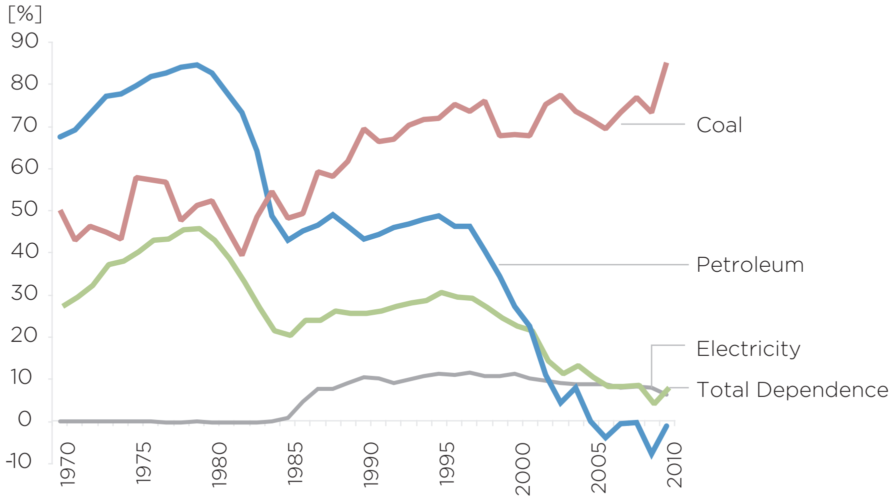

Figure 51 - Foreign energy dependence
Source: EPE, 2011.

The question of dependence and the high vulnerability of fossil fuel prices must be considered during the planning of additional generation for hydropowers in 2020 and 2050.

Furthermore, climate change mitigation actions and their impact on the country's regulatory environment, as well as on the final MWh cost, should be carefully considered in long-term planning. As seen in this report, values of the cost of greenhouse gas emissions at levels practiced today in countries like Australia and New Zealand can seriously undermine the competitiveness of power generation from these sources.

Final considerations

This paper has shown that there is still a long way to go to fully understand the adverse effects of climate change on the hydrological cycles in Brazil and especially on the domestic electricity sector. The definition of actions for adaptation to climate change based on this context becomes an even greater challenge when comparative global models are evaluated. The level of uncertainty in their application to the local situation makes it difficult - sometimes even impossible - to make decisions in line with current business models.

However, by adopting the climate risk management methodology, it was possible to adapt the analysis to the corporate reality for conditions of vulnerability of hydropower plants to historical natural climate variability processes. Knowing these impacts increases understanding of the conditions for managing risks associated to current processes, particularly those related to the quality of the sector infrastructure with regard to exposure to historical flows.

The analysis showed that the electricity sector has production units that are sensitive to exposure to variations in extreme seasonal flow. Knowing the goals of the business sector, the focus of this study was adjusted to follow the premises for the 2020 and 2050 time frames. Nevertheless, due to the applied methodology, the processes identified provide socioeconomic players with tools that can be used immediately to deal with the vulnerability to the natural climate variability.

The results achieved in the three case studies in power plants that generate electricity from water sources in Brazil have pointed to the need for understanding the conditions of the expansion of dependence on low-storage plants and/or complete dependence of flow energy.

In terms of energy security, the paper showed that the expansion in the use of renewable energy sources should always be evaluated in light of the complexities of the interactions among energy flow models and the system's variation patterns. Cost analyses must also incorporate assessments of their trade-off with respect to greenhouse gas emissions, in addition to the traditional environmental impact assessments.

In order to supplement evaluations of this issue in future analyses, it is essential to produce climatological, meteorological and flow data, and make them freely available, so that society and economic players have the opportunity to assess the historical and current vulnerability of each unit of the Brazilian electricity sector.

The pioneering conditions of this study characterize it as exploratory in nature, encompassing inherent uncertainties. The results of this analysis bring, however, important points to enhance the discussions on the vulnerability of the Brazilian corporate sector to natural climate variability and climate change.

The study was based on the analysis of three cases: a) power generation in a run-of-river plant with 30 MW installed capacity; (b) a plant with an installed capacity of up to 100 MW; c) a plant with a capacity of more than 1,000 MW; where the last two had reservoirs. For this purpose, river flow data of the plant location from the past 80 years was used. The plants are located in the Paraná basin and in the East/Southeast Atlantic basin.

The study indicates that the vulnerability of hydropower plants to the exposure of the variations in the flow of the rivers where they are located will vary according to their characteristics and size of installed capacity. The study further notes that the vulnerability of a plant also depends on the characteristics and management of the reservoirs and their installed capacity. Therefore, as a rule, plants that have reservoirs tend to have greater capacity for managing their vulnerabilities when these are scaled appropriately to their production conditions.

In examining the qualitative points detailed in the trade-off analysis, it is clear that it is important to diversify energy sources to ensure additional generation for hydropowers, especially when the cases studied here are considered. Consideration of renewable sources such as wind, photovoltaic and biomass was also shown to be significant. In the specific case of biomass, it proves to be more exposed to the risk of changes in water regime and local climate than the other two options. However, in this study the risk of this option was not quantified for the 2020 and 2050 scenarios because this assessment would require a specific study.

In the case of energy from fossil sources, these proved to be the most resilient to the impacts of natural climate variability and climate change, because its inputs and, consequently, its generation, suffer less influence from changes in water regimes. Nevertheless in the trade-off analysis, it is clear that these sources have quite a high exposure to risks associated to actions for mitigating GHG emissions.

During the study the future market trends for renewable sources was analyzed, and they showed cost reductions arising from government incentives, economies of scale in production and technological improvements. Therefore, there are investment opportunities associated to renewable sources, enhanced by a favorable regulatory environment for their use, in addition to public guidelines for encouraging sustainable development, particularly those associated to the challenges of mitigating GHG emissions in Brazil and in the world.

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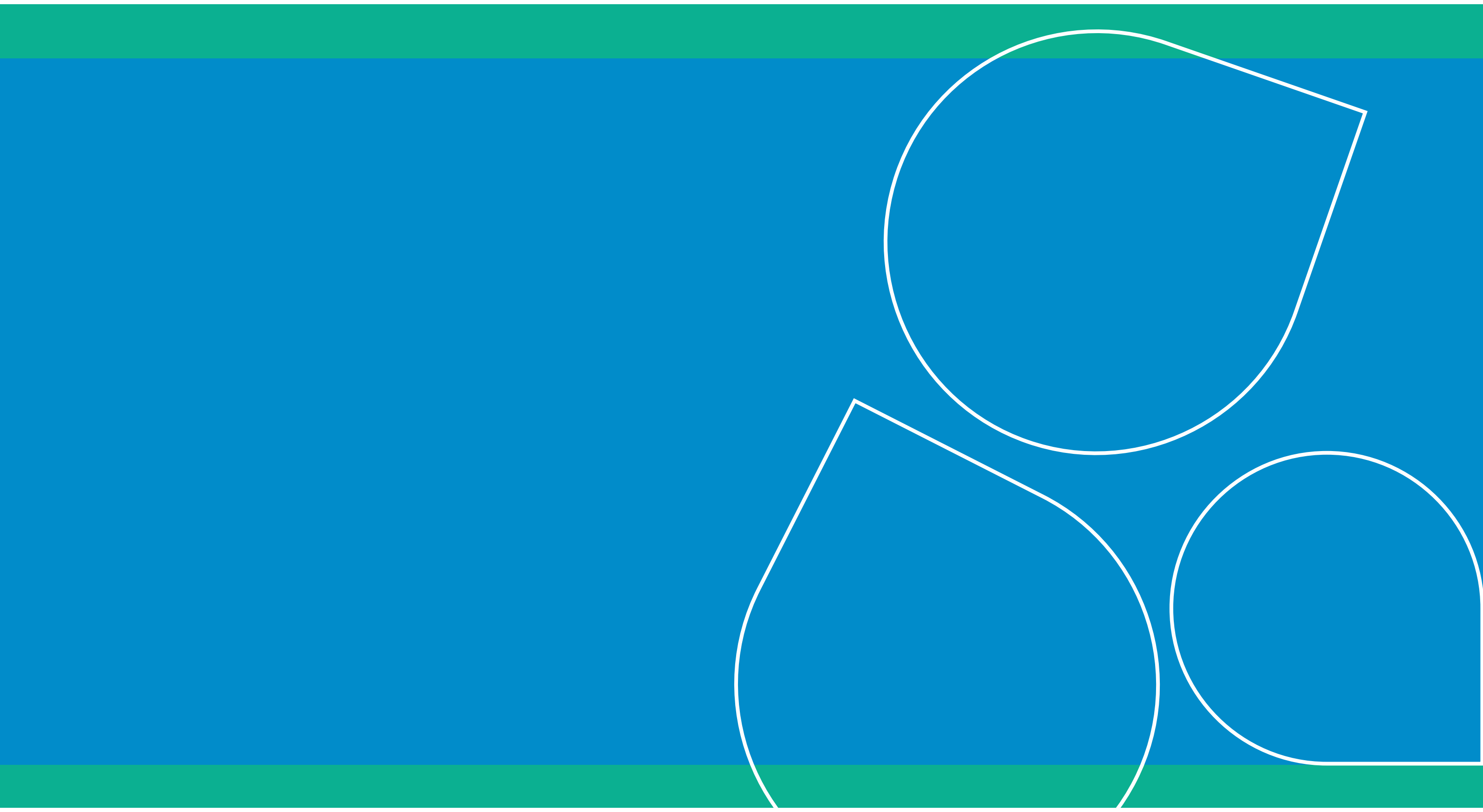

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