RIVER-BASIN MANAGEMENT AND HYDROPOWER SYSTEM IN REGULATED SECTORS. ENERGY MARKET, LEGAL FRAMEWORK, EXTERNALITIES, AND ENVIRONMENTAL RESTORATION IN THE LIGHT OF THE BRUMADINHO MINING DISASTER

GESTÃO DE BACIAS HIDRÁULICAS E SISTEMA HIDRÁULICO NOS SETORES REGULADOS DO BRASIL. MERCADO DE ENERGIA, QUADRO LEGAL, EXTERNALIDADES E RECUPERAÇÃO AMBIENTAL À LUZ DO DESASTRE NA MINERAÇÃO DE BRUMADINHO

Pedro Diaz Peralta [1]
Doutor em Direito
Yale School of Environment - Connecticut/USA

Abstract: This article addresses the issues of Hydropower generation as a sustainable resource that plays a critical role in Latin American countries' energy generation pool. Any factor capable of affecting quality, availability, the volume of circulating water, and an average flow of fresh waters, including water management of riverine, estuary, transfers, diversions, and channel systems, should be carefully analyzed. Cases affecting the electrical generation, distribution, and pricing system, add pressure to additional climate change issues arising from extreme weather events, such as drought or heat waves. This fact requires an adequate analysis of scenarios that pose a risk and compromise the electric system's reliability, such as water shortage and heat waves in tropical areas or heavy snowfalls in cold climates.

Keywords: Hydropower generation, Latin America, Brumadinho disaster.

Resumo: Este artigo aborda a questão da geração hidrelétrica é um recurso sustentável que desempenha um papel crítico nos países da América Latina no pool de geração de energia. Qualquer fator capaz de afetar a qualidade,

1 Dr. Peralta holds a Ph.D. in Law from Complutense University of Madrid. He is currently a researcher at the Complutense University of Madrid (Spain) and a Visiting Research at Yale University (2021-2023). He is a Senior Scientific Consultant at the Scientific and Technological Society GGINNS - Governance, Innovation, and Sustainability. Member of the AEDDA and AEDDS. He was a visiting professor at Harvard University from 2004-2008 and, a Member of the Spanish Cooperation with Latin America (Colombia) from 2009-2010, a visiting researcher at the University of Oxford in 2012. E-mail: pedro.dizperalta@yale.edu

disponibilidade, volume de água circulante e vazão média de água doce, incluindo a gestão hídrica dos sistemas ribeirinhos, estuários, transferências, desvios e sistemas de canais, deve ser cuidadosamente analisado. Casos que afetem o sistema de geração, distribuição e precificação de energia elétrica, adicionam pressão a questões adicionais de mudanças climáticas decorrentes de eventos climáticos extremos, como secas ou ondas de calor. Este fato exige uma análise adequada de cenários que representam risco e comprometem a confiabilidade do sistema elétrico, como escassez de água e ondas de calor em áreas tropicais ou fortes nevascas em climas frios.

Palavra-chave: Geração hidrelétrica, América Latina, desastre de Brumadinho.

INTRODUCTION

The Brumadinho dam collapse in January 2019 was a major environmental disaster in Brazil. Besides the ecological effects, the collapse's social and economic implications impacted all related sectors. As a result, the quality of the water supply for crop production and the general population was compromised. Keeping the river and basin systems in an excellent environmental balance has become a priority in Brazil for ensuring the sustainability and economical utilization of its natural resources, particularly in areas suffering from water shortages[2]. A particularly relevant aspect of the Brumadinho disaster was the potential impact on the electric system's reliability since Brazil is heavily dependent on hydropower generation. In this regard, the Retiro Baixo Hydroelectric Power Plant at Paraopeba River, downstream to the dam rupture point, helped mitigate the impacts of mudflow in the final areas of the Paraopeba basin but temporally disturbed the electric production balance in the area. Paraopeba is one of the main tributaries of the Sao Francisco River, the second-longest river in Brazil, flowing northward to the Atlantic Ocean.[3] Its basin also supplies water to the Greater Belo Horizonte region, housing 6 million inhabitants (26% of the population) and

---

2 DA SILVA SOUZA, T, DA SILVA FIGUEIRA BARONE, L., LACERDA, D., DOS SANTOS VERGILIO, C., VAZ DE OLIVEIRA, B.C. GOMES DE ALMEIDA, M., THOMPSON, F., REZENDE, C.E. *Cytogenotoxicity of the water and sediment of the Paraopeba River immediately after the iron ore mining dam disaster (Brumadinho, Minas Gerais, Brazil)*. Science of the Total Environment 775 (2021). DOI: https://doi.org/10.1016/j.scitotenv.2021.145193

3 DE SOUSA TEIXEIRA, D. FARIA VELOSO, M., VALADARES FERREIRA, F.L., GLERIANI, J.M., HUMMEL DO AMARAL, G., *Spectro temporal analysis of the Paraopeba River water after the tailings dam burst of the Córrego do Feijão mine, in Brumadinho, Brazi*. Environmental Monitoring Assessment (2021) 193: 435. DOI: https://doi.org/10.1007/s10661-021-09218-4

representing 40% of the total GDP of the state,[4] covering an area of almost 6000 km2 in Minas Gerais. The most appropriate uses of this basin, through its tributary system, are power generation, public and industrial supply, mining, and agricultural activities. Downstream from Retiro Baixo, the major Dam of Três Marias is located, a central point for regulating flows of the river Sao Francisco and for electric generation through the Mascarenhas Power Plant.[5]

The later development of the Sao Francisco Water Transfer Project (Transposição do Rio São Francisco[6]) aimed at supplying water to semi-desertic zones in the north of the country in the states of Ceará, Pernambuco, Paiba, and Rio Grande do Norte has highlighted the need of keeping in good quality the whole basin. Studies have estimated[7] that the economic activity in the basin represents over the 13% of Brazil's GDP. A relevant water flow is diverted through the Acaua-Araçagi channel (Canal das Vertentes Litorâneas) that supplies water to the Lower Paraíba River Basin.

Note the location of the Paraopeba river at the bottom of the map.

FIGURE I

4 DE MELO, M., OLIVEIRA NASCIMENTO, N., LISBOA VIEIRA MACHADO, F., OLIVEIRA LANCHOTTI, A. CASTRO MAIA, L. LEAL PACHECO, F.A., *Competition between multiple uses of water in the Belo Horizonte Metropolitan Area: the Paraopeba River water basin.* UNESCO, Second International Conference «Water, Megacities and Global Change» Pre-Conference 7-11 December.

5 TAVARES MARQUES, E., GUNKEL, G., SOBRAL, M. C. *Management of Tropical River Basins and Reservoirs under Water Stress: Experiences from Northeast Brazil*. Environments 2019, 6, 62; DOI: https://doi.org/10.3390/environments6060062

6 https://www.gov.br/mdr/transposicao-sao-francisco

7 DE MORAES, M. RIBEIRO, M.R. WATKINS D.W., VIANA, J. FIGUEIREDO, L., DA SILVA, G., CARNEIRO, A., Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil. Biofuels, Bioprod. Bioref. 10:255–269 (2016); DOI: https://doi.org/10.1002/bbb

Source: Tavares Marques, E., Gunkel, G., Sobral, M. C. *Management of Tropical River Basins and Reservoirs under Water Stress: Experiences from Northeast Brazil*.

Hydropower generation is a sustainable resource that plays a critical role in Latin American countries' energy generation pools. Any factor capable of affecting quality, availability, the volume of circulating water, and an average flow of fresh waters, including water management of riverine, estuary, transfers, diversions, and channel systems, should be carefully analyzed. Cases affecting the electrical generation, distribution, and pricing system, add pressure to additional climate change issues arising from extreme weather events, such as drought or heat waves. This fact requires an adequate analysis of scenarios that pose a risk and compromise the electric system's reliability, such as water shortage and heat waves in tropical areas or heavy snowfalls in cold climates.

The other side of the coin is the growing water demand in Brazil for crop irrigation, mainly for sugarcane production. However, in a context of scarcity of water resources aggravated by climate change's adverse effects, a significant dilemma is establishing priorities for water used for energy production, either directly for hydropower generation or indirectly for irrigation of biofuel crops. Several recently published papers introduce extensive evaluations for hydropower efficiency (including measures for pricing suppression) and the evolution of water demand for biofuels, mainly from sugarcane. In this context, an emerging question is whether it would be worth considering the energy markets and water resources management to improve the economic efficiency of resources intended for energy production. At the same time, preserving the integrity and quality of water resources becomes of paramount importance for ensuring the competitiveness and sustainability of the river system as well as social stability. In this aspect, the Brumadinho disaster should also be approached in terms of cross-sectoral competition for water supplies.

1 WATER RESOURCES REGULATION

Brazil has about 12% of the available fresh water on the planet. Agricultural production was the primary user representing approximately 54% of the water demand in 2010[8]. Water is an economic resource according to definitions of the

8 MORAES M, RINGLER C, CAI X, *Policies and instruments affecting water use for bioenergy production.* Biofuels Bioprod Bioref 5:431–444 (2011).

Brazilian Water Law[9] which has established some decentralized management organisms at the river basin level as the River Basin Committees (RBCs). Besides that, the Water Resources Councils have the legal powers to regulate the water pricing system[10] and capital for determining a cost-effective, environmentally sustainable, and economical, profitable management of basins.

Researchers have pointed out a growing potential for expansion of irrigated areas in Brazil, where only 5% of the harvested area represents 16% of total food production. Water requirements for irrigation of nine main crops estimated in 2007 in Brazil reveal the main trends in industrial crop production: from a total of 24.000 million m^3 available, up to 14000 million m^3 were used for sugarcane production has the higher water requirements. The Northeast region of Brazil, with great potential for expansion of cultivation, suffers extended drought periods. The Sao Francisco Water Transfer Project has the potential to regulate the availability of water for irrigation, but this could lead, by contrast, to water conflicts in regions like the Northeast, where water resources are scarcer than in other areas, also considering that global climate predictions foresaw changes in climate affecting the socio-economic development of agricultural-rich areas.[11] In other regions of Brazil, competency for water resources varies. In the Midwest region, irrigation is mainly intended to keep the soil in a good level of moisture, avoiding water stress. In the Southeast region, higher productivity per hectare is achieved in São Paulo agricultural holdings under permanent irrigation schemes.

The growing demand for bioenergy, stimulated by comprehensive energy policies in Brazil, suppose additional challenges to the management of water resources. In any event, and under an adverse climate change scenario, sugarcane is expected to expand in Brazil, raising the need to establish economic models to allocate sustainable water resources that can ensure sustainability while avoiding long-term adverse effects on vulnerable

9 BRAZIL, Federal Law nr 9.433. Water Resources National Policy. Brasília. Available at: http://presrepublica.jusbrasil.com. br/legislacao/104151/lei-9433-97

10 BRAGA B.P.F., STRAUSS, C., and PAIVA, F., Water charges: Paying for the commons in Brazil. Int J Water Resour Dev 21(1):119–132 (2005). "River Basin Committees (RBCs) play a central role by defining mechanisms and water charges, effectively establishing a water pricing system for the basin. Since Brazil is a federation, there are two kinds of water domains. The water domain is national if a river crosses more than one state. If a river is entirely inside a state, the water domain belongs to that state."

11 KROL, A.M., DE VRIES MJ, VAN OEL, P.R., and ARAÚJO JC, *Effects of small reservoirs on large scale water availability*, in International Environmental Modelling and Software Society - International Congress on Environmental Modelling and Software (IEMSs). I was modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada. Ed by Swayne DA, Yang W, Voinov AA, Rizzoli A and Filatova T (2010).

populations. This is also related to the unstoppable rise of petrol, gas, and other fossil fuel world prices leading to conflicting evidence that the water demand for sugarcane may enter into direct competition with the water supply for hydropower generation, which also has an impact on water policy related to biomass production, rather a “rural-based and labor-intensive production in less developed countries.”[12]

In a climate change adverse scenario, this competition among resources, ultimately intended to alleviate the continuous pricing increase in the energy markets and financial constraints altogether, requires a more detailed and in-depth evaluation and comprehensive economic analyses and impact assessment. This evaluation would provide the basis for more extensive joint programming and establishing appropriate monitoring and evaluation framework.

The other side of the dilemma is to what extent economic instruments, such as water pricing and water markets, can be used to avoid transferring negative environmental and economic impacts. Integrated financial modeling can be a valuable tool to support the design of effective economic instruments[13]. Water bioenergy systems show that water prices fail to reflect the real scarcity value of water in the regions. In addition, preliminary results of national-level economic long-term studies in Brazil illustrate the effects of increasing water charges for the agricultural sector. The benefits of water pricing policies based on financial modeling of bioenergy production require evaluating the policy impacts, particularly on the most vulnerable population[14].

Concerning the São Francisco River, the area covers 8% of Brazil, with most of the north section of the basin being semi-arid. Irrigation, public water supply, and power generation are the main uses for water stored in large reservoirs. The most demanding crops are fruits (mango and grape) and sugarcane. The valley is in a semi-arid region between the states of Bahia and Pernambuco. Still, today a central fruit-producing area in Brazil is an

---

12 DE MORAES, et al., Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil. Biofuels, Bioprod. Bioref. 10:255–269 (2016); DOI: https://doi.org/10.1002/bbb.1581

13 SMEETS, E, JUNGINGER, M, FAAIJ, A, WALTER, A, DOLZAN, P., TURKENBURG, W., *The sustainability of Brazilian etanol. An assessment of the possibilities of certified production*. Biomass Bioenerg 32:781–813 (2008).

14 RIBEIRO MAMF, VIEIRA ZMC, RIBEIRO MMR, *Participatory and decentralized water resources management: challenges and perspective for the Paraíba do Norte River Basin Committee*. Water Sci Technol 69(9):2007 to 2013 (2012).

example of a hydraulic policy.

Furthermore, establishing ecological river flows in this framework is an urgent need, with a view also to ensuring the electric system's reliability while guaranteeing supplies for covering essential demands. In other words, "to ensure power generation during periods of low inflow to lakes, a minimum amount of water can be released, which leads to conflicts with downstream users."[15]

2 REGULATORY FRAMEWORKS

Brazilian Act 12.187/2009 established the National Policy for Climate Change -NPCC. Act 12.187 is implemented by Executive Order 7.390/2010, adopting a target for reducing greenhouse gas emissions from 36.1% to 38.9% by 2020. This Executive Order, in line with the National Policy for Climate Change, establishes that the sectoral plans for the mitigation and adaptation to climate change will cover the generation and distribution of electricity. Institutional implementing instruments should include the Interministerial Committee on Climate Change, the Brazilian Research Network on Climate Change, and the Coordination Committee of Activities in Meteorology, Climatology, and Hydrology.

On the regulatory side, and in narrow connection with the disaster's environmental impact, the Brazil Act on climate provides the legislative basis for enforcement in line with the constitutional principles for sustainable development. Hence the need to strengthen governmental institutions' reaction to improving the governance and regulatory tools available to avoid any further disruptions of those sensitive areas and reduce expected impacts.

The alignment of Brazil with the Sustainable Development Goals.[16] The principle of sustainable development is enshrined in Brazilian Act 12.187/2009, which established the National Policy for Climate Change -NPCC. Act 12.187 is implemented by Executive Order 7.390/2010, which compromises a greenhouse gas emissions reduction from 36.1% to 38.9% by 2020[17]. the Act states that economic and social development must be compatible with the protection of the climate system (Article 4). The institutional implementing instruments

15 DE MORAES, et al., Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil. *Biofuels, Bioprod*. DOI: https://doi.org/10:255-269 (2016)

16 WEDY, G. *Climate legislation and litigation in Brazil*. *Sabin Center for Climate Change Law*. Columbia Law School October 2017. http://www.ColumbiaClimateLaw.com

17 WEDY, G. *Op. cit*. 2017. http://www.ColumbiaClimateLaw.com

should be included: the Interministerial Committee on Climate Change, the Brazilian Research Network on Climate Change, and the Coordination Committee of Activities in Meteorology, Climatology, and Hydrology.

This Executive Order, in line with the National Policy for Climate Change, establishes that the sectoral plans for the mitigation and adaptation to climate change will cover the generation and distribution of electricity, public transportation, interstate heavy cargo transportation systems, chemical industry activities, steel and mining, health services and agribusiness among others. In the following years, Brazil achieved significant emissions cuts thanks to efforts to reduce deforestation in the Amazon and shift the electric system toward energy generation from hydropower and other renewable sources, including wind, solar, and biomass. The new environmental policies hindered those achievements from 2019 onwards.

The changes in priorities when the new Bolsonaro government took office were shifted in the opposite direction. Shortly after that, the Brazilian Foreign Ministry notified the Secretariat of the UN Framework Convention on Climate Change (UNFCC) in November 2018 that Brazil was withdrawing its candidacy to host the 25th Session of the Conference of the Parties, or COP 25, of the UN Climate Change Convention. The conference, finally held in Madrid from November 11 to 22, 2019, was dedicated to negotiating the implementation of commitments achieved with the Paris Agreement on Climate Change in 2015 (COP 21).

Brazil, the world's eighth largest economy and sixth largest emitter of greenhouse gases, withdrew from leadership on climate change. Although targets for reducing emissions are not legally binding, Brazil initially committed to cutting emissions by 37 percent by 2025 plus an "intended reduction" of 43 percent by 2030, using 2005 levels as the baseline; the radical changes in new policies introduced, nevertheless, critical challenges to Brazil's environmental policies, which impacted goals of ecological protection and affected international commitments.

The country was caught between global forces – the efforts to protect some of the most sensitive and pristine wilderness, including the Amazon rainforest, versus the desire to develop critical commodities. As an example, some donor countries of the REDD+ programs- Reducing Emissions from Deforestation and Forest Degradation (in the framework of the United

Nations Framework Convention on Climate Change[18] have frozen or withdrawn their contributions in the absence of a clear commitment from Bolsonaro's Government to comply with the previous agreements in protecting the rainforest from degradation. Those funds are channeled mainly through the so-called Amazon Fund[19]. Although participating in REDD+ programs is not legally binding for the beneficiary countries when they don't make sufficient efforts to mitigate actions, namely incompatible with REDD+ programmers in the framework of the Convention on Climate Change (UNFCCC). Other additional reasons, such as increasing the availability of grazing areas and pastures for cattle, have also been invoked to justify the Amazon Fund cuttings mentioned above, which indubitably point to output in de facto practices of the Brazil administration.

2.1 APPLICABLE PUBLIC POLICIES

Brazilian Act 12.187/2009 established the National Policy for Climate Change - NPCC. Act 12.187 is implemented by Executive Order 7.390/2010, adopting a target for reducing greenhouse gas emissions from 36.1% to 38.9% by 2020. This Executive Order, in line with the National Policy for Climate Change, establishes that the sectoral plans for the mitigation and adaptation to climate change will cover the generation and distribution of electricity.

Institutional implementing instruments should be included: the Interministerial Committee on Climate Change, the Brazilian Research Network on Climate Change, and the Coordination Committee of Activities in Meteorology, Climatology, and Hydrology.

2.2 CORRECTIVE LEGISLATIVE MEASURES

Among the proposed legislative changes, in progress, under study, in parliamentary procedure, popular initiative, etc., we can refer to the following:

1. The prioritization of mining in the central region of Minas Gerais promoted the concentration of resources, leading many areas of the state, specifically the Paraopeba region, to be dependent on economic and social aspects.
2. The three spheres of public power and civil society participate

18 Available at http://www.fao.org/redd/en/ The last accessed on Jul 12, 2021.

19 Available at http://www.amazonfund.gov.br/en/home/ The last accessed on Jul 22, 2021.

differently that materialize in a bureaucratized, timid, discontinuous, and disorganized way when promoting or sustainably supporting the region's development.

3. The strengthening of a more egalitarian relationship between the State and Civil Society from the construction of a space for dialogue to seek endogenous models and strategies for the development of sustainable tourism in the region can be a decisive factor for the resumption of sustainable growth in the area.

3 HYDROPOWER GENERATION

Hydropower supplies up to 95% of the demand in Brazil. But since the beginning of the XXI century, a significant challenge has been expanding electricity production without massive use of fossil fuels.[20]

The expansion in nominal hydropower capacity in 2010 was not followed by higher hydropower generation. Severe droughts in the southeast of Brazil and intense heat waves impacted hydropower production from a maximum in 2011 (449 TWh), further reducing about 10% below.[21] In this regard, the 2019 Brumadinho Dam Disaster had a significant repercussion on the integrity and stability of affected rivers and fluvial systems, where the measures following the alteration of hydraulic flows following the environmental disaster and the subsequent and urgent need to adopt mitigation, reduction, and restoration measures quickly, represented a qualitative shift in the decision-making process and restoration policies of affected rivers. This consideration also accounts for the access and usage of energy systems in Brazil, where the pricing approach, inside the generation mix, is mainly hydro generation.[22]

Gas combined-cycle generation has increased in the meantime. It is on the way to becoming the second source of electricity in coming years, mainly due to the erratic nature of wind and solar production compromising the objectives for reducing greenhouse gas (GHG) emissions previously committed. Although the electricity market has been undergoing in the last years a gradual process of deregulation aimed at improving the efficiency of generation and distribution systems, keeping a stable flow in the main

20 BELANÇON, M.P., Brazil electricity needs in 2030: trends and challenges.2015. DOI: https://doi.org/arXiv:2009.11281

21 BELANÇON, M.,P. Op. cit., 2015.

22 SANTOS, T. N. , D.L., SABOIA, C.L. CABRAL, N. L., CEQUEIRA, F. *Hourly pricing and day-ahead dispatch setting in Brazil: The dessem model*. Electric Power Systems Research. Volume 189, December 2020

basins should be a policy priority, including disaster management, since perturbations “also have direct consequences in the electric pricing through the adjustment between electric generation and electric demand.”

3.1 MAIN CHALLENGES

Brazil has today about 85 GW of hydroelectric dams and 12 GW of run-of-river hydropower. Still, several relevant studies suggest an increase of two to three times in demand in the 2030´s decade, seriously compromising the reliability of the system in the future: “Even although scenarios do not consider an increase in annual hydropower production, in all of them hydro needs to provide higher power for more time, mainly at the end of the summer (February/ March).In 2018 the Hydropower generation in Brazil delivered more than 70 GW for only 12 hours, reaching 429, 289, and 360 in the scenario 2030. This result indicates an increased risk for the national grid, once the maximum hydropower available is often constrained due head loss in the reservoirs, which has already played a central role in the last energy crisis in the country.”[23]

As discussed by several authors,[24] the operator of the national grid has made some favorable decisions to transfer water without respecting, in many cases, ecological and technological minimum flows[25], making inadequate planning and estimation of demand trends, or not taking into account the total balance of hydropower system to avoid disconnections and blackouts´ risks[26].

23 BELANÇON, M.P., Brazil electricity needs in 2030: trends and challenges. DOI: arXiv:2009.11281

24 DE MORAES, et al., Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil. *Biofuels, Bioprod*. DOI: https://doi.org/10:255-269 (2016)

25 HUNT, D. J, NASCIMENTO A., SCHWENGBER TEN CATEN, C., CAPUTO TOME, F.T., SMITH SCHNEIDER, P. RIBEIRO THOMAZONI, A. L, CASTRO, N.L., BRANDAO, VASCONCELOS DE FREITAS, M.A., COLOMBO MARTINI, J. S., SOARES RAMOS, D., SENNE, R., *Energy crisis in Brazil: Impact of hydropower reservoir level on the river flow*. Energy, Volume 239, Part A, 15 January 2022, 121927. https://doi.org/10.1016/j.energy.2021.121927 “*The dams that should be filled first to reduce the requirement for thermal electricity are Jurumirim, Tres Marias, Sobradinho, Furnas, Emborcaço, Nova Ponte, Serra da Mesa, then Paraibuna. After the reservoirs are filled up, the average level of the pools at the end of October should be 78% and the hydropower plants in the cascade should operate with a capacity factor of 50%. This low-capacity factor will allow the hydropower potential to generate electricity when there is no solar or wind power in the grid. Which in turn allows more solar and wind power to be added to the grid without the need for new storage solutions.*”

26 DE MORAES, et al., Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil. Biofuels, Bioprod. Bioref. 10:255–269 (2016); “*like \to spill some of the water in the Furnas Reservoir wasting hydroelectric potential, to increase peak generation in the Grande and Parana Rivers, and reduce thermoelectric generation”. This kind of management has worsened the energy crisis experienced in 2014-2015. In the scenario, 2030d hydropower should supply more than 70 GW by only 10 hours. In such a projection, hydropower would supply only 80% of what is has generated in 2018, and the results indicate that such aggressive conservation should be necessary in order*

3.2 PRICING SYSTEM AND WATER REGULATION

Since the 1990s, the electricity market has undergone gradual deregulation[27]. Transmission and distribution, however, are monopolies in nature. It is necessary to consider the monopolistic microeconomic theory to make them more efficient.

The costs of the electric power sector are usually recovered altogether in the traditional systems. Today, however, the prices are recovered in disaggregate modeling due to the breakdown of the fees covering the activities of generation, transmission, and distribution.

The design of electrical distribution tariffs should consider a fair cost allocation. Each consumer, that is to say should pay a fraction of the service cost. How is that cost fashioned? It may be reached in two ways: using the theory of economic marginality or the cost causality principle. Furthermore, tariffs must be capable of managing both consumption and generation patterns. The two-part tariff in electricity distribution started in France, where it was known as the green tariff. This nonlinear pricing approach is widely used in public utility pricing.[28] Designed to control peak and off-peak demand, the two-part tariff considers a fixed fee related to the access charge and the usage price. It optimizes the energy system and defines different tariff products based on the generation technology mix[29].

By offering a two-part tariff menu, electrical distribution companies (DISCO) enable consumers to pick the tariff most suitable to the load profile. By providing two-part tariffs, DISCOsmay thus increases its economic efficiency. That is, companies may establish tariffs that maximize the welfare of both the customer and the distribution company.

3.2.1WATER PRICING SYSTEM IN SÃO FRANCISCO RIVER BASIN

to keep about the same level of power demand from hydro experienced in 2018. On other hand, during winters hydropower could operate most of the time at reduced power compared to 2018, though another problem emerges as reducing hydropower below 25 GW may not be practical because some minimum water flow is required. Additionally, one may expect that higher penetration of intermittent power sources will increase the rate at which hydropower increases and decreases"

27 STEELE SANTOS, P.A., CORADI LEME, R., GALVAO, L. *On the electrical two-part tariff—The Brazilian perspective*. Energy Policy 40 (2012) 123–130

28 Have a look at WILSON ROBERT,1993; BORGER, 2000; SCHLERETH,2010.

29 ROMAN, J. GOMEZ, T., MUNOZ, A., PECO, J.,1999. *Regulation of distribution network business*. EEE Transactions on Power Delivery 14(2),662–669.

In 2008, the São Francisco River Basin Committee (CBHSF) established a water pricing system for the basin which the National Water Resources Council approved.[30] The water users in São Francisco Basin have been paying for water since 2010. The system considers three types of yearly water volumes: abstracted water, water consumption, and effluents discharged into the rivers. Each of these volumes has a Public Unitary Price (PPU) in Reais per cubic meter, established through the deliberation of the SFRB Committee.

3.2.2 WATER PRICING SYSTEM IN PARAÍBA DO NORTE RIVER BASIN

"The basin is located in Paraíba state (Northeast Brazil), the most important basin under the Paraíba state domain. This basin is well characterized by two geographical and hydrological zones: the semiarid and the coastal zone. There are many water conflicts in the basin, mainly between the water supply and irrigation sectors. Considering the coastal zone, sugarcane is one of the most important irrigated crops. The Paraíba do Norte River Basin Committee (CBH-PB) has been installed since 2007. The CBH-PB discussed and approved mechanisms and values for a water pricing system. During these discussions, the irrigation sector hesitated to pay for bulk water, while other stakeholders (water supply and industry sectors) debated that all users must pay for water. Finally, after negotiations, a water pricing system was agreed upon. The maximum water charge was defined as US$ 0.006/m3 (industry), and the minimum."[31]

From a nonlinear pricing approach, applying a two-part tariff to electricity distribution networks is the primary pricing approach used in Brazil, where the generation mix is mainly hydro-generation. In the case of Brazil, a two-part tariff may also be considered for network analysis[32]. Correa da Silva et al. have considered a value of 20 TWh/year in 2004, while the most recent estimate by EPE was about 31 TWh/year for 2017, including losses. In the higher band, Cruz et al. have estimated that in 2020 this amount of energy from renewable resources should be close to 55 TWh/year. On the other hand, Cardemil et al. estimated the showerhead load probable of an average day by

30 DE MORAES, et al., Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil. *Biofuels, Bioprod*. DOI: https://doi.org/10:255-269 (2016)

31 DE MORAES, M. RIBEIRO, M.R. WATKINS D.W., VIANA, J. FIGUEIREDO, L., DA SILVA, G., CARNEIRO, A., *Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil*. Biofuel, Bioprod. Bioref. 10:255–269 (2016)

32 Steele Santos, P.A., Coradi Leme, R., Galvao, L.. *On the electrical two-part tariff—The Brazilian perspective*. Energy Policy 40 (2012) 123–130

considering an annual consumption of 33.7 TWh, including losses for 2012. In this way, it would be reasonable to estimate potential savings due to SWH at about 50 TWh per year in 2030.[33]

3.3 ENERGY POVERTY

Energy poverty is considered one of the determining factors in the processes of social exclusion in modern times.[34] Limited access to essential energy services is a common problem affecting a vast percentage of the Latin American population. Still, it worsens in countries with low production and substantial presence among poor people, such as Brazil.[35]

On-going work includes testing and verifying an integrating biofuel model for Brazil[36] aimed to evaluate the impacts of agricultural sector water pricing, including the effect on water use, resulting in impacts on GDP and poverty; a hydro-economic model is needed to assist in policy decisions by estimating the potential benefits of water pricing decisions for the extended basin for improving demand management and efficient water use.[37]

3.3.1 CLIMATE CHANGE IMPACT ON ELECTRIC GENERATION

Their discontinued characteristic constraints wind and solar power. Besides that, thermal energy in Brazil was historically provided by biomass, which is seasonal depending on the climate. However, biomass has been surpassed by Gasred thermal power in the last few years. Only two nuclear reactors are running in Brazil, and the share of nuclear is not expected to change significantly in the next decade since there is only one reactor in the construction phase, which was halted in 2014[38].

Filling the gaps between the supply of intermittent sources and demand is fundamental to ensuring the reliability of the Brazilian electric system. In 2030 it is assumed that only wind and solar shall have enough flexibility to

33 STEELE SANTOS, P.A., CORADI LEME, R., GALVAO, L.. On the electrical two-part tariff—The Brazilian air. Energy Policy 40 (2012) 123–130.

34 GUZORSKI, C. MARTIN, M., ZABALOY, M. *Energy poverty: conceptualization and its link to exclusion. Brief review for Latin America*. Vol. 24, 2021. Revista Ambiente et Sociedade. Special Issue: Energy territories http://dx.doi.org/10.1590/1809-4422asoc20200027r2vu2021L2DE

35 GUZORSKI, C. et al. Op. Cit., 2021.

36 MORAES M, RINGLER C, Cai X, Policies and instruments affecting water use for bioenergy production. Biofuels Bioprod Bioref 5:431–444 (2011).

37 DE MORAES, et al., Integrated economic models to support decisions on water pricing in biofuel production river basins: three case studies from Brazil. Biofuels, Bioprod. Bioref. 10:255–269 (2016).

38 BELANÇON, M.P., *Brazil electricity needs in 2030: trends and challenges*. arXiv:2009.11281

cover the additional 137 TWh needed, resulting in a solid fitment to developing those sources.

"Brazil's climate mitigation strategies are contained in its Nationally Determined Contribution (NDC). To do so, we employ the computable general equilibrium MIT Economic Projection and Policy Analysis model and simulate alternative carbon pricing scenarios (sectoral versus economy-wide carbon markets) to achieve the country's overall emissions targets announced under the Paris Agreement. The results show relatively cheap emissions reductions from land-use changes and agriculture in the short run: the cost of the Brazilian NDC is predicted to be only 0.7 percent of GDP in 2030 (Gurgel et al., 2019).[39] Further efforts to reduce carbon emissions beyond 2030 would require policy changes since all the potential emissions reductions from deforestation would be finished, and the capacity to expand renewable energy sources would be constrained. In this case, an economy-wide carbon pricing system would substantially help avoid higher compliance costs"[40].

Climate change is one of the most critical risks threatening the planet today and in the future. Solutions to this problem likely require cooperation at a global level.[41] The 2015 Paris Agreement is the broadest and most inclusive international agreement to address climate change globally. Under the Agreement, developed and developing countries have proposed measures to reduce greenhouse gas (GHG) emissions over the next decade. Under the Paris Agreement, it has announced plans to cut its emissions by 37 percent by 2025 and 43 percent by 2030 (relative to 2005) in its Nationally Determined Contribution (NDC) - UNFCCC in 2016. To achieve these targets, the Brazilian NDC highlighted its intentions to decrease deforestation, reforest degraded land areas, expand renewable energy sources, increase energy efficiency and intensify agricultural and livestock production. In this context, it is highly relevant to understand the costs associated with these commitments and alternative policy options to achieve them.

There are already several studies about GHG emissions control in Brazil. Several authors investigated the impacts of carbon taxes on the Brazilian

39 GURGEL, ANGELO C; PALTSEV, SERGEY; GUSTAVO VELLOSO BREVIGLIERI. *The impacts of the Brazilian NDC and their contribution to the Paris agreement on climate change*. Environment and Development Economics; Cambridge Vol. 24, Iss. 4, (Aug 2019): 395-412.

40 GURGEL, Angelo C; et al. Op. Cit., 2019.

41 KROL, A.M., DE VRIES, M.J., VAN OEL, P.R. AND ARAÚJO, J.C., Effects of small reservoirs on large scale water availability, in International Environmental Modelling and Software Society (IEMSs). International Congress on Environmental Modelling and Software. Modeling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada. Ed by Swayne DA, Yang W, Voinov AA, Rizzoli A and Filatova T (2010).

economy. In 2010, EMCB analyzed the costs of reducing deforestation in the Amazon region, heavily deploying biofuels into the energy mix, and adopting carbon taxes. Still, each of these mitigation options was considered individually in alternative models. "Emissions from land-use changes and agriculture retain larger shares in total emissions during the projection. Total emissions reflect expected economic growth, increased use of fossil fuels in the energy mix, and the expansion of the agricultural sector. The economic growth rate is one of the most important drivers of emissions in the BAU scenario. These rates range from 2.48 to 2.80 percent per year between 2015 to 2050 and align with IMF projections, except for the first five years (until 2020), which have a slightly higher growth rate in EPPA."[42]

4 BRUMADINHO DISASTER

Brumadinho dam collapse happened in January 2019 at the Córrego do Feijão iron mine in the Minas Gerais state, compromising water quality and availability for power generation, crop production, water supply, and sanitation services for the general population.

A previous Brazilian mining disaster, also known as the Samarco disaster, occurred on 5th November 2015 at the Fundão dam close to Mariana city, Minas Gerais State. The mud wave was roughly estimated to account for 43 million m^3 reaching the Doce River, the second-longest river in Brazil. This river served as a primary source of water and fish for several local communities. Pollutants carried out by the mud to Doce River were delivered to the Atlantic Ocean, traveling around 665 km and seriously affecting coastal environments and marine ecosystems, including the Abrolhos Marine National Park. Both collapsed dams, Fundão and Corrego do Feijão belong to Vale SA, the company which owns 133 iron ore dams in Brazil, of which 80 % of them, 105, are located in the Minas Gerais State. Vale uses both downstream and upstream tailings dams. The model used in Brumadinho and Mariana's upstream tailing dam is made by vertically accumulating the tailings through successive uphill deposition[43].

Concurring extreme situations of accidents involving ruptures in tailings

42 GURGEL, ANGELO C; PALTSEV, SERGEY; GUSTAVO VELLOSO BREVIGLIERI. *The impacts of the Brazilian NDC and their contribution to the Paris agreement on climate change*. Environment and Development Economics; Cambridge Vol. 24, Iss. 4, (Aug 2019): 395-412.

43 SILVA ROTTA, L.H., et al The 2019 *Brumadinho tailings dam collapse: Possible cause and impacts of the worst human and environmental disaster in Brazil*. International Journal of Applied Earth Obs Geoinformation.

dams, which were used to store wastewater generated during ore processing (Mariana and Brumadinho), results in a total estimated cost, including production losses, and fines and damages, of US$13.48 billion.[44] The area affected by the collapse of the Córrego do Feijão dam covers a vast region in Brumadinho municipality, 20 km southwest of Belo Horizonte, the capital of the state of Minas Gerais. Further south is the Santuário do Bom Jesus de Matosinhos, in Congonhas, a World Heritage Site by UNESCO for its Baroque arquitecture. Minas Gerais state has in addition three natural, high-value natural landscapes: Mata Atlántica, Cerrado and Caatinga.

The development model imposed in the region Paraopeba-Brumadinho, a subsidiary of the great Paraiba do Sul basin, aggravated the consequences of the collapse of the Córrego do Feijão dam, which led the area to a situation of socio-environmental, cultural, and economic crisis. With the economic development linked with mineral exploration, tourism and services showed increased activity in the region of Brumadinho, strongly induced by the opening of the Inhotim Museum. Considering the public policy and the experiences built, as well as the general guidelines, the question to answer is to what extent Brumadinho can, implements a new model of sustainable development of local, rural activities, which has as its centrality the sociocultural experience of its inhabitants in the coexistence with the efforts of environmental preservation in the region. The role played by official entities – Municipality, State, and Union – should be pivotal in developing local, sustainable development plans.

REFERENCES

BELANÇON, M.P., **Brazil electricity needs in 2030**: trends and challenges, 2015. DOI: https://doi.org/arXiv:2009.11281

BRAGA BPF, STRAUSS C AND PAIVA F, **Water charges**: Paying for the commons in Brazil. Int J Water Resour Dev 21(1):119–132, 2005.

DA SILVA SOUZA, T, et al. Cytogenotoxicity of the water and sediment of the Paraopeba River immediately after the iron ore mining dam disaster (Brumadinho, Minas Gerais, Brazil). **Science of the Total Environment** 775, Feb. 2021. DOI: https://doi.org/10.1016/j.scitotenv.2021.145193

DE MELO, M., et al., C**ompetition between multiple uses of water in the**

44 SAPATA GONZALEZ, R., et al., *Economic and financial consequences of process accidents in Brazil: Multiple case studies*. Engineering Failure Analysis 132 (2022) 105934

Belo Horizonte Metropolitan Area: The Paraopeba River water basin. UNESCO, Second International Conference «Water, Megacities and Global Change» Pre-Conference 7-11 December.

DE MORAES, et al., **Integrated economic models to support decisions on water pricing in biofuel production river basins**: three case studies from Brazil. Biofuels, Bioprod. (2016); DOI: https://doi.org/10.1002/bbb1581

DE SOUSA TEIXEIRA, D. et al., Spectro-temporal analysis of the Paraopeba River water after the tailings dam burst of the Córrego do Feijão mine, in Brumadinho, Brazil. **Environmental Monitoring Assessment** (2021) 193: 435.

DOI: https://doi.org/10.1007/s10661-021-09218-4

FORMIGA-JOHNSSON, R., KUMLER LM, LEMOS MC. **The politics of bulk water pricing in Brazil**: lessons from the Paraíba do Sul River Basin. Water Pol 9:87–104, 2007.

GURGEL, Angelo C, et al. The impacts of the Brazilian NDC and their contribution to the Paris agreement on climate change. **Environment and Development Economics**; Cambridge Vol. 24, Issue 4 (Aug 2019):395-412

GUZORSKI, C. MARTIN, M., ZABALOY, M. Energy poverty: conceptualization and its link to exclusion. Brief review for Latin America. Vol. 24, 2021. **Revista Ambiente et Sociedade**. Special Issue: Energy territories DOI: http://dx.doi.org/10.1590/1809-4422asoc20200027r2vu2021L2DE

HERRERA-MARTINEZ S., et al., Analysis of socio-economic impacts of sustainable sugarcane-ethanol production by means of inter-regional Input-Output analysis: Demonstrated for Northeast Brazil. **Renew Sustain Energ** Rev 12(28):290–316, 2013.

KROL, A.M., DE VRIES, M.J., VAN OEL, P.R. AND ARAÚJO, J.C., Effects of small reservoirs on large scale water availability, in International Environmental Modelling and Software Society (IEMSs). **International Congress on Environmental Modelling and Software**. Modeling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada. Ed by Swayne DA, Yang W, Voinov AA, Rizzoli A and Filatova T, 2010.

MAGALHÃES, J.L; ROCHA, L.; VASCONCELOS. C.A. **O Município e a Construção da Democracia Participativa**. Belo Horizonte: Mandamentos, 2006.

MORAES M, RINGLER C, Cai X, Policies and instruments affecting water use for bioenergy production. **Biofuels Bioprod Bioref** 5:431–444, 2011.

NUNES, CRP; DE MORAIS JUNIOR, KML. Companies in the export and import sector analyze a historical import economic legacy in the XXI Century. In: David A. Frenkel (ed. lit.), Anna Chronopoulou (ed. lit.) **Business, economics and mercantile law**: selected issues, 2016, págs. 101-111. Disponible at https://dialnet.unirioja.es/servlet/articulo?codigo=6698121 Access on Fev 12, 2021.

RIBEIRO MAMF, VIEIRA ZMC, RIBEIRO MMR, Participatory and decentralized water resources management: challenges and perspective for the Paraíba do Norte River Basin Committee. **Water Sci Technol** 69(9):2007 to 2013, 2012.

ROMAN, J., GOMEZ, T., MUNOZ, A., PECO, J., Regulation of distribution network business. **EEE Transactions on Power Delivery**14(2),662–669. 1999.

SANTOS, T. N., et al. Hourly pricing and day-ahead dispatch setting in Brazil: The dessem model. **Electric Power Systems Research.** Volume 189, December 2020, DOI: https://doi.org/10.1016/j.epsr.2020.106709

SAPATA GONZALEZ, R., DA SILVEIRA ROSSI, R.A., MARTINS VIEIRA, L.G., Economic and financial consequences of process accidents in Brazil: Multiple case studies. **Engineering Failure Analysis** 132 (2022) 105934

SILVA ROTTA, L.H., et al. The 2019 Brumadinho tailings dam collapse: Possible cause and impacts of the worst human and environmental disaster in Brazil. **International Journal of Applied Earth Geoinformation.** DOI: https://doi.org/10.1016/j.jag.2020.102119

SMEETS, E., JUNGINGER, M., FAAIJ, A., WALTER, A., DOLZAN, P., TURKENBURG, W., The sustainability of Brazilian etanol. An assessment of the possibilities of certified production. **Biomass Bioenerg** 32:781–813 (2008).

STEELE SANTOS, P.A., CORADI LEME, R., GALVAO, L. On the electrical two-part tariff—The Brazilian perspective. **Energy Policy** 40 (2012) 123–130

TAVARES MARQUES, E., GUNKEL, G., SOBRAL, M. C. Management of Tropical River Basins and Reservoirs underWater Stress: Experiences from Northeast Brazil. **Environments** 2019, 6, 62. DOI: https://doi.org/10.3390/environments6060062

THOMPSON, F. DE OLIVEIRA, B.C., CORDERO, M. Severe impacts of the Brumadinho dam failure (Minas Gerais, Brazil) on the water quality of the Paraopeba River. **Science of the Total Environment** 705 (2020) 135914

UBA DE ANDRADE, M.A., Valin, H. Soterroni, A.C., Ramos, F.A, Halo, A., Exploring future scenarios of ethanol demand in Brazil and their land-use implications. **Energy Policy** 134 (2019) 110958.

WEDY, G. Climate legislation and litigation in Brazil. Sabin Center for Climate Change Law. **Columbia Law School** October 2017. http://www.ColumbiaClimateLaw.com. Accessed on Mar 11, 2021.

Recebido: 10.07.2021
Revisado: 26.08.2021
Aprovado: 30.09.2021