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CHAPTER 1

Belo Monte through the Food-Water-Energy Nexus: the disruption of a unique socioecological system on the Xingu River.

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1. Introduction

The Xingu River has headwaters in the heart of the ancient central Brazil shield and travels northwards for circa 2000 km until reaching the Amazon River (Figure 1). The Xingu stands out not only as a major tributary of the Amazon River, but also because of its unique riverine landscape. It forms a huge and abrupt curve of 130 km length regionally known as the Volta Grande of Xingu (Big Bend of the Xingu) before it reaches the lowlands of the Amazonas sedimentary basin at a place known as Belo Monte; a location that lends its name to the most expensive and controversial infrastructure project in Brazil's history. The objective of this chapter is to unpack the Belo Monte dam case using a nexus lens that considers the relationships and feedbacks between different system components, with a particular focus on water, energy and food. We argue that the adoption of a more integrated approach can allow better governance decisions to manage Belo Monte's impacts across the various sectors.

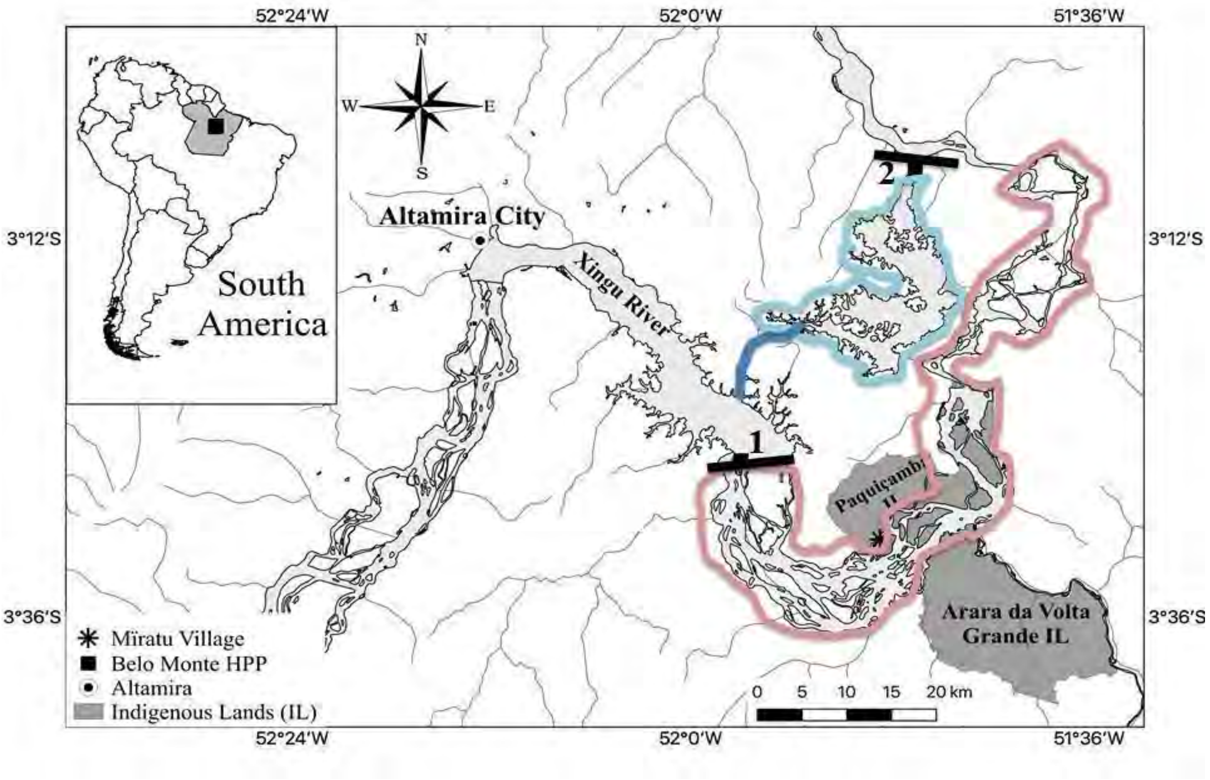

Figure 1. Belo Monte hydropower plant (HPP) at the Volta Grande of the Xingu, Pará, Brazil. The axis of each dam is represented by a black bar: 1. Pimental and 2. Belo Monte dams. The colored contours represent, respectively, the diversion channel (dark blue), the Intermediate reservoir (light blue) and the dewatered sector of the Volta Grande (reddish).
Source. Elaborated by the authors.

Belo Monte engineering involves a dam in the Xingu mainstem (Pimental dam) to form a reservoir (Xingu reservoir) allowing the diversion of most of the Xingu's discharge through an artificial channel that feeds a second reservoir (Intermediate reservoir) within an impounded valley, flooding dry lands and former stream channels. Most of the water now flows through this artificial system, leaving the Volta Grande with a fraction of its original discharge, with direct effects on two Indigenous Lands (ILs), two riverine communities and hundreds of scattered families that have the traditional riverine lifestyle and subsistence basically dependent on fish for food and income (Adams et al., 2017; Francesco et al., 2017). The building of the dam started in 2011, and the two impoundments were completed in September 2015, forming the Xingu reservoir, the diversion channel, the Intermediate reservoir, and the de-watered Volta Grande. Belo Monte was completed in November 2019, when the last of the 18 turbines started functioning at the main powerhouse in the Intermediate reservoir dam. Although the amount of water deviated is proportional to the quantity of energy to be produced due to the run-of-the-river design, the higher the water volume deviated from the river, the greater the impacts on the Volta Grande socioecological system.

The effects of this engineering feat on the socioecological system cross-cut water, energy and food are severe. The relationship among these sectors can be framed as a nexus or point of connection, whereby actions and decisions in one part of the system or in one sector, are recognized to have important impacts on, and interdependencies with, the other parts of the water-energy-food triad (Bazilian et al., 2011). Taking a nexus approach can be a useful way to understand the interactions between each part of the system, drawing upon available data and model projections (Keskinen et al., 2016). A nexus approach can also inform decision making so that proper risk assessments and mitigation measures can be enacted prior to development activities, supporting evaluations that use approaches such as Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA). It further offers a way of supporting policy alignment and coherence across sectors (Smajgl et al., 2016).

Nexus approaches are becoming increasingly important in decision making because they show that impacts of dams are rarely restricted to the sites where they are located. For example, the implications of the Belo Monte hydropower complex are far reaching and span multiple temporal and spatial scales, affecting different aspects of the environment and society (Stringer et al., 2018). Indigenous and traditional riverine communities are often already marginalized and lack a voice in decision making, even though they are severely impacted by dam construction in terms of land expropriation, subsistence, and livelihood opportunities. A nexus approach can help identify where inequalities might be exacerbated and reinforced, similar to approaches such as the Integrated Water Resources Management (IWRM) (Stringer et al., 2021), albeit with a broader focus on interlinkages across sectors.

Yet, the nexus approach is not without criticism for viewing water, energy and food purely as resources, while neglecting the ecological or environmental processes that extend beyond such a resource conceptualization (Grenade et al., 2016). In the Belo Monte case, the two dams affect the water and sediment flows, with consequences on the downstream and upstream floodplains and fisheries. Furthermore, the nexus in the Amazon is also interlinked with other factors to the same degree as climate and land use changes, which can be particularly disruptive in the Brazilian context where there is a heavy reliance on hydropower and natural resources that support people’s livelihoods (Mercure et al., 2019). The rainy season in the Amazon is driven by the South American Monsoon System (SAMS), which is active during the austral summer (Marengo, 2004). The Amazon rainforest is a critical element of the SAMS and supports the recycling and long-distance transport of moisture (Lovejoy & Nobre, 2018) to central and southeast Brazil, supplying water to most rivers with installed hydropower plants in those regions. Hence, deforestation across the Amazon Basin is another threat to water and energy security in Brazil. Forest loss combined with climate change (IPCC, 2021) can lead to severe reduction in water availability and hydropower generation in the Xingu River (Stickler et al., 2013; Sorribas et al., 2016), strengthening water conflicts in the Volta Grande.

2. The Brazilian licensing system and policy

The Brazilian licensing system was legally established in 1986, through the creation of the Environment National Policy (SISNAMA, 1986) and subsequent resolutions, as well as State licensing laws mirroring the federal resolution. The main document for evaluating any large enterprise project is the Environmental Impact Study (Estudo de Impacto Ambiental/EIA) and must be considered in decision-making. The national licensing agency is the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA, Portuguese acronym here and thereafter) through its Environmental Licensing Directory (DILIC). The DILIC technical staff may access any other studies and information available to support the licensing process, and they usually do, but the decision is based on the EIA in a three-step process: the Previous Licensing (Licença Prévia, LP), Installation Licensing (Licença de Instalação, LI) and the Operation Licensing (Licença de Operação, LO). After obtaining the Previous Licensing, the Basic Environmental Plan (PBA) is the guideline document which has to be presented for attaining the Installation License. The PBA includes the monitoring, mitigating, management and compensating programs during implementation and operation of the enterprise. A critical factor that hinders this system to effectively prevent or mitigate social and environmental losses is an interpretation of the Licensing Law. The National Environment Council (CONAMA) determines since 1986 that the Entrepreneur is responsible to present and conduct studies, programs and reports, without establishing independent oversight mechanisms (SISNAMA, 1986). Studies are mostly conducted based on hiring private consulting companies according to the rules of the private sector, obeying the business-as-usual and marketing rules. The contracting company has control over what is to be included, demonstrated, suggested, and interpreted so that the consulting company is compelled to defend the interests of the contracting party. Additionally, the consulting company is usually bound by contract rules, in which the consultants sign confidential contractual clauses that forbid them from commenting, writing, and publishing anything without the express authorization of their contractor. Complete databases generated by the consultancy are given to IBAMA, which makes them publicly available, but there is no control, either from IBAMA or from other independent stakeholders, of processes occurring between data collection and data submission. In the Belo Monte case, the EIA was developed by Leme (2009), a private consultancy company with extensive experience in licensing governmental infrastructure projects.

Thus, consulting companies act in accordance with market interests and continue to neglect the social and environmental impacts sometimes stated in their own official reports. This situation applies to the Belo Monte case, in which the systematic neglect of predicted impacts in the official reports, which were vehemently contested by fisher families and leaders, led the Miratu Yudjá community to start their own independent monitoring, in partnership with several research institutions (Pezzuti & Carneiro, 2015).

3. The Amazon’s River pulsing system

The Flood Pulse Concept (FPC) proposed by Junk et al. (1989) detailed how the complex and intertwined aquatic and terrestrial ecosystems combine to create a uniquely dynamic environment. The Aquatic Terrestrial Transition Zone (ATTZ) role is thoroughly described, and its unique features hold the key factors explaining the high productivity of seasonally flooded ecosystems, such as the igapó forests of clear water Amazonian rivers, such as the Xingu.

The combination of the monsoon climate and a geological framework favored the formation of a continental-scale flooding pulse system and the world's largest river basin, the Amazon River and its tributaries (Welcomme, 1979; Junk, 1997; Goulding, 2013). The magnitude of a flooding pulse has both spatial and temporal dimensions that affect the entire ecosystem. Floodplain plants adapt their biological cycles to the seasonal inundation, usually synchronizing flowering and fruiting with the high-water season. Flooding peaks and relief determine the extension of seasonally flooded areas and, therefore, the amount of feeding and spawning habitats for the aquatic fauna. The duration of flood represents the amount of time to feed, grow, and to complete the reproductive cycle.

Amazonian seasonally flooded habitats are crucial for the global carbon budget. These are the most species-rich floodable forests on Earth, which, in addition to its many endemic tree species, also provide shelter and habitat for numerous aquatic and terrestrial species of invertebrates and vertebrates, many of them restricted or seasonally dependents to these environments (e.g. Goulding, 1988; Haugaasen & Peres, 2005; Bezerra et al., 2010; Schöngart et al., 2010; Junk et al., 2015). These forests have plenty of diversified suitable microhabitats for fish reproduction. Fruits, nuts, leaves, stems and other plant parts furnish the food chain basis for an incomparable freshwater community. The floodplains host some of the most diverse freshwater wildlife in the world, including the richest community of fishes with over 3,000 species (Dagosta & de Pinna, 2019; Oberdorff et al., 2019). Other important groups of herbivores that depend to different degrees on the flooded forests include 15 species of freshwater turtles and the Amazon manatee (Vogt, 2008). Top predators, which play an important role over the entire food chain, include four species of crocodilians, two of otters and three river dolphins, apart from carnivorous fishes and several birds that feed on aquatic prey.

Despite the long history of human presence along the Xingu River and intense use of natural resources, hundreds of fish species and several turtles are still abundant in the basin. In fact, the Xingu River holds one of the highest known diversity of fish in the Amazon Basin (Pérez, 2015; Winnemiller et al., 2016). Said diversity and productivity are intrinsically related to the magnitude of the seasonal flooding pulses (Castello et al., 2015; Isaac et al., 2016; Pinaya et al., 2016; Bayley et al., 2018; Castello et al., 2019), which in the past supported a human population that was likely twice the current one (Prestes-Carneiro et al., 2016). Turtles (Podocnemididae), for example, have been widely used by autochthonous human inhabitants of the river floodplains. Their relevance to the local subsistence persists despite a history of often unsustainable exploitation (Freitas et al., 2020). For example, from the early 1700s, the Portuguese colonizers developed a system to produce and export turtle egg-oil, using indigenous labor and knowledge (Bates, 1864) in a wasteful and unsustainable manner that endured for at least 200 years (Pereira, 1954; Smith, 1974). Yet, Podocnemidid river turtles are still abundant all over the basin, including *Podocnemis unifilis* (Alcântara et al., 2013), and *P. expansa,* particularly in the lower Xingu (Carneiro, 2017).

This magnificent aquatic diversity and productivity also favored intense occupation of the floodplains by humans, and the development of cultures adapted to a riverine way of life coupled to the hydrological cycles. Even today, the people living along the margins of major Amazon River tributaries have one of the highest daily fish consumption levels in the world, reaching up to 800g per capita/day (Corrêa et al., 2014). Fishing has adapted to a spatial and temporal mosaic of ecological contexts and opportunities, with gears, techniques and bait being used accordingly. The Xingu River dwellers are not an exception, and their diet is based on fish and manioc (Almeida, 2018; Mesquita, 2020). Since the beginning of the Belo Monte dams' construction, fish consumption is declining in the region, especially at the *Volta Grande* of Xingu (Pezzuti et al., 2018).

4. The Amazing Volta Grande of the Xingu River: a turbulent pulsing system

The extensive Amazonian rapids are still poorly known, despite the fact that they hold a unique fauna and flora, many of which adapted to living in fluvial environments with high water velocity, as the rheophilic fishes (Winemiller et al., 2016). The Xingu, and the Volta Grande stretch in particular, is composed of a complex array of braided bedrock channels with several abrupt bends, powerful rapids, and abundant low waterfalls, characterizing the most prominent rheophilic environment in the entire Amazon basin. The Xingu River clear waters associated with these extensive rapids led to the development of the most diverse rheophilic fish fauna of the Amazon (Perez, 2015), with at least 45 species exclusively inhabiting the Xingu rapids. This condition also characterizes a highly productive system during the low-water season, and it is responsible for the development of the unique aquatic flora and fauna.

5. Belo Monte's threats to the seasonally flooded ecosystems of the Xingu River

Amazonian large-river wetlands cover an area of 750.000 km2 and are classified by varying sediment and nutrient loads of river waters, which are traced to the geology of their catchments (Junk et al., 2011). While most of the sediment- and nutrient-rich white-water rivers drain the Andes highlands and foothills, black- and clear-water rivers drain terrains of the Guyana and Central Brazilian Shields with exposed crystalline rocks or that are covered by sandy soils. Their water has a lower content of suspended solids, with reduced concentration of electrolytes, and is acidic. While black-water rivers have a dark, reddish-brown color that derives from the accumulation of dissolved organic compounds from adjacent sandy forest soils, clear-water rivers, such as the Trombetas, Tapajós, Xingu and Araguaia-Tocantins, usually have mostly transparent to greenish waters. Clear-water rivers are most common in the eastern part of the Amazon basin, and their upper and middle courses are characterized by diverse rocky beds dominated by sediment bypassing (Wittmann and Junk, 2016). The Xingu floodplains encompass an area of approximately 37,000 km2, of which about 90% covered by different types of vegetation (Melack & Hess, 2010).

The amplitude between low and high-water levels in the middle-lower course of the Xingu amounts to 4-5 m on average, with the highest water levels occurring in March-April and the lowest water levels occurring in September-October (Schwatke et al., 2015). The floodplain forest of the Xingu can be divided into pioneer vegetation mostly composed of open shrub and tree formations established on the rocky islets, on riverbanks and along sandy bars, whereas stabilized sandy bars form slow-water areas susceptible to the deposition of fine-grained sediments (silt and clay) covered by closed-canopy forests (igapó forest, sensu Prance, 1979). Flood height and duration exert considerable control on tree species composition and diversity because floodplain tree species have developed specific morpho-anatomical (i.e., aboveground root systems, hypertrophied lenticels) or physiological (i.e., leaf-shedding during the high-water period, often combined with growth reduction or cambial dormancy, timing of reproductive phenology to the high-water period, etc.) adaptations to flooding (i.e., Schöngart et al., 2002; Wittmann et al., 2016; Householder et al., 2021).

The Belo Monte hydroelectric complex has an unprecedented effect on the igapó flora and fauna. These impacts are caused, mainly, by (1) permanent flooding of igapós upstream of the Pimental dam, (2) significant reduction in stream discharge and water levels in the Volta Grande area, particularly during the high-water season, and (3) flood-pulse changes downstream of the Belo Monte dam.

Although the impacts of altered flood regimes on the Xingu igapó flora are yet to be studied, results from other hydropower dams in the lowland Amazon reported dramatic effects. These include mass mortality of flood-tolerant tree species at the higher flood-levels, as well as the replacement of flood-adapted tree species by secondary ones originating from the adjacent terra firme in the upper, less flooded parts of the floodplain (i.e., Assahira et al., 2017; Lobo et al., 2019; Schöngart et al., 2021). These environmental impacts may extend to the river courses over hundreds of kilometers (Resende et al., 2019). In addition, the temporal shift of low- and high-water regimes disturbs reproductive cycles and energy storage of many floodplain tree species, which have adapted to the seasonal predictability of the flood pulse during hundreds of thousands of years. Ultimately, endemic tree species of the Xingu River will be most endangered through extinction at regional scales, with still-unknown consequences for the aquatic and terrestrial food chains, along with the traditional use of floodplain resources by humans (Schöngart et al., 2021). Further impacts, such as the reduction in sediment- and nutrient transport, trophic changes through reduced stream flow and elevated water temperatures, and the loss of hydrological connectivity are certain, although not yet studied.

6. The so-called “Consensus Hydrograph”, the Belo Monte energy generation and the de-watered Volta Grande of Xingu

The amount of water diverted from Volta Grande defines the Belo Monte’s energy generation. The water diversion to the dam occurs according to a monthly hydrograph known as “Consensus Hydrograph” (Leme, 2009), a contentious name given the absence of any local stakeholders other than the entrepreneur, the national electricity company (Eletrobrás) and the National Electric Energy Water Agency (ANEEL) in its elaboration. This hydrograph scheme imposes a severe dewatering of the Volta Grande, limiting the peak wet-season discharge to 4,000 m^3/s and 8,000 m^3/s (Hydrograph A and B) in alternate years, respectively, while keeping the dry-season discharge to levels as low as 700 m^3/s. These represent a diversion of 81.5% and 72.2% of the river's historical peak discharge, respectively.

According to the Brazilian Constitution, the licensing legislation and the EIA, the Belo Monte complex should maintain the biodiversity, the ecosystem services, and the river-dependent livelihoods, including their subsistence practices and food security. Despite the risks that such a change to the local flow would represent, the licensing agency (IBAMA) did not assess its ecological consequences. Yet, the EIA of Belo Monte (Leme, 2009) pointed out that a peak discharge of at least 15,000 m^3/s during the wet season would be necessary to allow an expressive flooding pulse in the Volta Grande and, thus, the maintenance of the seasonal ecological processes, including the access of flooded environments to freshwater wildlife. River turtles, for instance, are able to access the floodplains for feeding only when the discharge reaches a minimum of 13,000 m^3/s. An independent study conducted by the Juruna indigenous community of Miratu village, in partnership with researchers from the Federal University of Pará (UFPA) and the Socioenvironmental Institute (ISA), has shown that fishes would need similar conditions to access floodplains for feeding and spawning (Pezzuti et al., 2018; Zuanon et al., 2021). The same study concluded that the minimum discharge of 700 m^3/s during part of the dry season would hinder navigation conditions for riverine communities living along the de-watered reach. Despite these facts, the operation of Belo Monte under the "Consensus Hydrograph" was authorized. Eleven years later with Belo Monte hydropower complex working at its full capacity, a complementary study conducted by the operating company (Norte Energia, 2020) confirmed that Hydrographs A and B would prevent the inundation of respectively 35,600 ha (99.6%) and 30,748 ha (86.4%) of the seasonally flooded ecosystems along the Volta Grande. The impacts that had been projected in the official EIA study (Leme, 2009), including decreased fish catchability, altering fish-landing composition, effects on the physiology and growth of fish species, and decreasing fish consumption by indigenous and traditional families living in the area impacted by Belo Monte, have materialized since 2016 (Norte Energia, 2018; Almeida, 2018; Pezzuti et al., 2018; Mesquita, 2020). Fish consumption, for example, has decreasing since 2013 (Lopes et al., submitted). Despite the numerous studies attesting to direct and indirect effects of hydropower dams on aquatic wildlife (Moll, 1997; McAllister et al., 2001; Moll and Moll, 2004; Pérez, 2015), fisheries, regional food security and quality of life (Marmulla, 2001), the official monitoring program (Plano Básico Ambiental, or PBA) claims that the negative effects on the socioecological system in the Volta Grande cannot be a causally linked to the hydrological changes in the Xingu imposed by Belo Monte (Norte Energia, 2018).

The independent monitoring led by the Juruna indigenous people denounces the gravity of the ongoing collapse of the region due to hydrological changes caused by Belo Monte (Pezzuti et al., 2018). In 2016, the first year after the damming of the Xingu River, was also the driest year of the basin since the beginning of discharge monitoring in 1931. In 2016, the peak discharge of the Xingu reached only 10,000 m^3/s due to a severe drought, which is half of the historical average of 20,000 m^3/s (Table 1).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sept	Oct	Nov	Dec	Sum	Reduction* %
Mean monthly discharge m/s (1931-2008)	7720	12736	18139	19985	15591	7065	2877	1563	1066	1115	1870	3735	93462	-
Year of 2016	2442	6379	7798	10693	6127	2732	1550	890	745	991	1635	3726	45708	51.1
Provisional IBAMA Hydrograph	3100	10900	14200	13400	5200	1800	1300	900	750	760	1000	1200	54510	41.7
Consensus Hydrograph A	1100	1600	2500	4000	1800	1200	1000	900	750	700	800	900	17250	81.5
Consensus Hydrograph B	1100	1600	4000	8000	4000	2000	1200	900	750	700	800	900	25950	72.2

Table 1. Historical monthly average discharge of Xingu River at Altamira.
Source. National Waters Agency (ANA, https://www.snirh.gov.br/hidroweb/).
* Compared to the average annual discharge (1931-2008)

Flooding was minor, even though the river discharge was significantly higher than both Hydrographs A and B. The occurrence of a historical dry year just after river impoundment brought synergistic impacts and provided evidence that ecosystems will be more threatened with the presence of dams under climate change, which is expected to increase the duration and intensity of the dry season in the eastern Amazon (IPCC, 2021). The year of 2016 was nicknamed by the Juruna as the "year of the end of the world", as it marks a dramatic scenario of decrease in the water flow and high mortality of fish and tracajás (Podocnemis unifilis), a culturally important river turtle species.

The Juruna's engagement in carrying out independent monitoring of the impacts of Belo Monte has been a fundamental instrument in the struggle for the rights of the peoples of Volta Grande and a response to the unreliable assessments underestimating impacts that mark the dam's licensing and operation processes. In the words of Natanael Juruna, "We are not monitoring only our own death nor the death of fish and tracajás. Our monitoring is aimed at defending life in the Volta Grande of the Xingu and at stopping the Consensus Hydrograph" (translated from Portuguese).

The water diverted from the Volta Grande is causing an unprecedented permanent drought condition never before experienced in the region, possibly surpassing the water-discharge variations observed in the last 4,000 years (Bertassoli Jr. et al., 2019). Volta Grande water comes from the central Brazil highlands and depends on the Amazon Rainforest and Cerrado forest covers, not only in the Xingu Basin, but in the whole Amazon to supply moisture for the inland propagation of the South American Summer Monsoon (SASM). Thus, rainfall over the Xingu Basin depends on the presence of the Amazon forest (Stickler et al., 2013; Lovejoy & Nobre, 2013), where less forest means less water for the Xingu. The availability of water in the eastern Amazon, where the Xingu flows, could further decline in the coming decades with climate change (IPCC, 2021). Some studies suggest that climate change could lead a reduction up to 50% in the Xingu's flow in the coming decades (Sorribas et al., 2016). The dam project was made based on the availability of water based on data from previous decades, a period when the Xingu Basin had greater forest cover and when the threat of anthropogenic climate change was still poorly understood. Therefore, the hydroelectric plant is outdated, with its design unsuitable to operate in a sustainable way under current and future hydrological conditions. The current climate change and deforestation scenarios could further intensify the conflict over water imposed by the "Consensus Hydrograph".

Conflicts over the Volta Grande's waters date back to a first attempt to establish a dam in the region, during the Brazilian dictatorship period: a hydropower project known as Kararaô. Despite the highly adverse political moment, Kararaô was halted, while Belo Monte was not, even though the latter has likely faced fierce opposition, at least since 2009, when the claims to have access to the public audiences of the project were denied. The construction was paralyzed several times due to occupation of construction sites and due to judicial decisions, but the building of the dams and the diversion channel and reservoirs soon returned due to powerful political pressures. In November 2020, another year severely affected by drought and amid the COVID-19 pandemic, and five years after the release of the installation license for the Belo Monte hydropower plant, indigenous and riverine peoples in Volta Grande, for the second time, occupied and paralyzed the BR-230 Highway (Transamazônica) for five days. Once again, they denounced the serious impacts of the Belo

Monte water diversion, as manifested in their occupation letter, “We are here with our lives to defend Xingu’s life. Belo Monte wants to kill us slowly, as it is doing with the Xingu, with plants, animals, fish. But let’s not die without screaming. We are here showing our cry for water and life. Stop killing us! Stop stealing the waters of the Xingu!” (Translated from Portuguese).

The Belo Monte hydropower engineering modus operandi has continued to feed the conflict over the Xingu’s water. Despite an installed capacity of 11,233 MW, the natural variation in the river flow only guarantees the effective average capacity of 4,571 MW (Leme, 2009) and only at the social and ecological expenses of the Consensus Hydrograph. As of today, after rounds of political and judicial battles, IBAMA has made a controversial agreement with Norte Energia and authorized the operation of Hydrograph B in February 2021. On June 16th, attending a petition from the Public Ministry, a Judge suspended the operation and demanded the adoption of the Provisional Hydrograph suggested by the technical Board of IBAMA, but the demand was ignored by the President of the institution. Norte Energia’s reply came through an indirect attempt to terrorize society, by using the media to argue that the non-adoption of the Consensus Hydrograph would represent an average energy generation capacity loss of 1,800 MW in 2022. According to them, this loss would imply an additional cost of 3.5 billion Brazilian Reais (around US$ 700 millions) for the Integrated National System (Sistema Integrado Nacional, or SIN), which has an overdependence on hydropower.

In addition to the social and ecological impacts in the Xingu, recent studies have shown that the Belo Monte hydropower plant emits a significant amount of greenhouse gasses (GHG). Despite its run-of-the-river design, the Belo Monte hosts large reservoirs that inundated dry lands and favored conditions for emissions of carbon dioxide (CO2), and especially methane (CH4), which are generated from flooded vegetation and soils. The Belo Monte reservoirs emitted from 15 to 55 kg CO2eq MWh−1 during the first two years of operation, increasing three times the GHG emissions in the area compared to pre-impoundment emissions (Bertassoli Jr. et al., 2021). Projecting future GHG emissions from Belo Monte is a complex issue because they will depend on both future water availability (which has a nexus with global climate change and Amazon deforestation) and the hydrograph used for energy generation.

Finally, it is important to note as well that a nexus approach is, perhaps, insufficient for assessing the full impacts on the socioecological system. Wider system pressures are also important because dam construction is linked to other large infrastructure enterprises. For example, the Volta Grande is also threatened by another major project: a mining installation by the Canadian company Belo Sun Mining Ltda. The Volta Grande mining project aims to become the largest open-pit gold mine in the country. Less than 50 km from the main dam of the Belo Monte hydropower plant and 9.5 km from the Paquiçamba Indigenous Land (IL), the project envisages the use of cyanide in the management of ore minerals - an extremely toxic substance for both aquatic and terrestrial ecosystems - and the project's environmental studies predict that the risk of mining dam failure would be high.

7. Conclusions

This chapter has shown how the damming of the Xingu River to build the Belo Monte hydropower plant has severe detrimental impacts for marginalized societal groups across all aspects of the water-energy-food nexus. Those people who are most dependent on natural resources and maintenance of the river flooding pulse for their survival have strongly resisted this development, yet their voices remain unheard. Given projected climate change, increasing deforestation, significant GHG emissions and increased frequency of severe droughts, the energy production from the Belo Monte hydropower plant is called into question, raising issues about its feasibility to deliver what was intended in terms of stable output of clean renewable energy. The Belo Sun environmental impact assessment fully ignores both the impacts of Belo Monte in the region and the detrimental combined effects that these two large projects will likely have on the local socioecological system. This example demonstrates that, while the water-energy-food nexus offers a useful conceptual start in understanding interlinkages across sectors that span the social and ecological parts of the system, an explicit focus on governance remains vital to capturing the interplay among multiple interventions on the whole system. Stringer et al. (2018) argue that consideration of a second nexus, a policy-institutions-knowledge nexus, is central to improved governance, so that detrimental ecological impacts can be reduced and more equitable outcomes achieved for all. In the context of sustainable development and making progress towards the United Nations Sustainable Development Goals (SDGs), if Brazil is to advance and ensure that Agenda 2030's vision that "no one gets left behind" is considered, then far-reaching changes are needed in terms of the governance systems that underpin decision making about large infrastructure developments in order to more comprehensively assess and mitigate their adverse socioecological outcomes.

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