Challenges in the sustainability of hydroelectric projects in the Brazilian Amazon.

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Abstract

In Brazil hydropower development represents a mean for achieving the UN Sustainable Development Goals (SDGs) at national level. Currently the Amazon region is the epicenter of hydropower development in the world, given the numerous hydroelectric projects in the planning, construction, and operation pipeline. The participation of the Amazon in the generation of energy continues to increase despite its global environmental and ecological value. In Brazil from 2015 to 2018, approximately more than half of the constructed energy infrastructure was hydroelectric, surpassing wind, solar, biomass and thermal energy. The urban areas in the Amazon region are also considered the fastest growing in Brazil, many presenting development gaps in access to basic infrastructure services, such as electricity, potable water, and sanitation. This regional gap in access contrasts to the large amounts of power generated at hydropower plants in the Amazon, and distributed through the national grid. The paper presents an overview of the main sustainability challenges surrounding the development of two hydroelectric projects in the Brazilian Amazon, and challenges in providing access to affordable, reliable, sustainable and modern energy for all, as defined in SDG 7. The findings are based on infrastructure assessments case studies made with the Envision® rating system holistic methodology on two hydroelectric plants operating in the Jari river, and in the Madeira river; as well as input from field research done in both project sites as part of the Harvard Brazil-Cities Initiative. The findings on the challenges surrounding the two hydropower projects in the Amazon can influence future development towards sustainability and resilience. The main social and environmental challenges are related to the impacts surrounding the implementation of the reservoirs, dams, and the preexisting lack of basic infrastructure services. The main challenges are organized according to the Envision categories: 1) Quality of Life, 2) Leadership, 3) Resource Allocation, 4) Natural World, 5) Climate and Risk.

Keywords
Hydropower development, sustainability, Amazon region, climate change, SDG7, renewable energy, planning, Brazil, Envision rating system
Introduction

Clean and affordable energy is considered a keystone for sustainable development with impacts in economic growth, social progress and environmental sustainability. The UN Sustainable Development Goal (SDG) 7: Clean and Affordable Energy, looks into ensuring access to affordable, reliable, sustainable and modern energy for all (UNDP, 2016). Access to energy has effects on communities' economic growth, food production, health, clean water, security, wellbeing, education, employment and gender equality (UNDP, 2016).

The global demand for electricity is expected to increase more than 70%, according to the trends and projected growth of global energy needs.1 Hydropower has become the leading renewable energy source globally, supplying about 71% of all renewable electricity in the world, which accounts for 16.4% of the world’s electricity from all sources.2 Due to constant water flow, hydropower has the capacity to provide reliable power generation, low-cost base-load power, and ability to respond to high peaks. With an average global growth rate of about 4%, there has been a rise in hydropower development in emerging markets, which includes Brazil.

Two of the targets set by SDG 7 for 2030 are to ensure universal access to affordable, reliable and modern energy services, as well as to increase substantially the share of renewable energy in the global energy mix. Brazil has been increasing the share of renewable energy through hydropower development, which has been the favored option for large-scale power generation development (MPDG, 2016). From 2015 to 2018, hydropower represented approximately 58% of all the energy infrastructure built, surpassing wind, solar, biomass, and thermal (SEPAC, 2016).

Today the Amazon Basin is considered the epicenter of hydropower development in the world. The Brazilian government goal is to double the Amazon’s share of power generation from 10% to 20%, and ultimately to 43% (MIN-PRDA, 2012; PAS, 2008; MP, 2016). Many large-scale infrastructure projects in the energy sector, have been planned for 2020, a total of $120 billion, to meet this goal.

The participation of the Amazon in the generation of energy continues to grow. About 85 hydropower plants are planned as part of Brazil’s Acceleration Growth Program (PAC).3 These projects constitute approximately the 8% of the Brazilian top 20 investments in infrastructure with more than US $25 billion investment.4 These projects are at different stages of completion: about 39% in planning and bidding, 43% in construction, and 18% completed and in operation.

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1 IEA, 2015. World Energy Outlook, Factsheet: Global energy trends to 2040
3 Programa de Aceleração do Crescimento (PAC).
4 PAC projects status as of 2016: 15 preparatory action, 18 licitation, 21 construction permits, 16 construction, 9 completed, 6 operation.
Challenges in the Sustainability of Hydropower Projects in the Amazon.

Due to the large-scale influence of hydropower development, it is a challenge to mitigate significantly the social and environmental impacts. Hydropower development can produce irreversible destruction of habitat; displacement of local population, destruction of Indigenous lands, interruption of the water flows, and overall changes in the environment.

Hydropower development has a large potential in increasing the amount of renewable energy available and reducing further the carbon intensity of the Brazilian energy matrix. Major national and regional strategic development plans, such as Brazil’s Acceleration Growth Program (Programa de Aceleração do Crescimento, PAC), the Sustainable Amazon Region Plan (Plano Amazônia Sustentável, PAS), and the Amazon Regional Development Plan (Plano Regional de Desenvolvimento da Amazônia, PRDA), consider the hydropower potential of the Amazon to be underdeveloped, using only 10% (11,203.9 MW) of its 112,039 MW potential, which would be equivalent to 43% of the national hydroelectric potential, 259,668 MW (MIN-PRDA, 2012; PAS, 2008; MP, 2016).

In the Amazon River Basin there are about 775 cities, which are considered the fastest growing in Brazil and some cities are expanding at a double rate. According to the Sustainable Amazon Plan (PAS), rapid urbanization, coupled with the shortcomings of public policies and investments related to the occupation of urban land, water supply, sanitation, solid waste management and job creation, has put millions of people living in the Amazon in unhealthy housing, both in metropolitan areas, as in towns and inland villages.5

The projections in the planning and implementation of hydropower in the Amazon should account for the full social and environmental costs that this development requires. Not having such knowledge leaves authorities with inadequate analysis of the impacts that these projects have on the local communities perpetuating the unplanned urban growth compounded by the lack of basic infrastructure services.

There are various deficiencies in the hydropower planning process that affect the sustainability of the development. At the beginning of a project there are deficiencies in the scoping practice of environmental impact assessments, which are the building block for any project permitting process. Public participation is limited at the scoping period, there is limited focus on impacts, and it tends to concentrate on describing the baseline conditions (Borioni et al, 2017). These deficiencies lead to delays and do not help prevent conflicts during public consultation at later project phases (Borioni et al, 2017).

Two Cases: Hydropower plants located in the Jari River and in the Madeira River.

The two hydropower plants cases selected for study are located in the Jari River and the Madeira River. The Jari River is a northern tributary of the Amazon River, and the Madeira River is one of the largest tributaries of the Amazon River. Both plants are named Santo Antonio, but are unrelated projects. The surrounding context of each of these plants is different, as the location of the Santo Antonio do Jari is remote, in the municipality of Laranjal do Jari with population of about 40,000; while the Santo Antonio plant in the Madeira river is next to Porto Velho city with population of about 500,000. These plants are part of the cohort of finalist case study projects analyzed with the Envision tool, as part of the Infrastructure 360° Awards, an initiative led by the Inter-American Bank and Harvard University Zofnass Program for Sustainable Infrastructure.

Together these two plants generate electricity for more than 49 million people. The hydropower plants can generate more power when located near waterfall locations. This

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7 Harvard University Zofnass Program for Sustainable Infrastructure, Infrastructure 360° Awards, accessed in July 2018, https://research.gsd.harvard.edu/infrastructure360/about/
is the case for both Jari and Madeira rivers, where both plants were developed to harness power in locations near waterfalls.


Figure 4. Madeira River in 2008, the Teotônio waterfall (lower left), and Porto Velho city (upper right). Source: Google Earth Pro, 2018.

Figure 5. Madeira River in 2018, the Teotônio waterfalls are covered by water after the construction of the hydroelectric. Source: Google Earth Pro, 2018.
The Santo Antonio hydroelectric plant located in the Madeira River, is considered to be one of the largest hydroelectric plants in Brazil and in the world. It is located downstream of the Jirau hydroelectric plant, both part of the Madeira River Complex. It is amongst the 15 largest and represents an investment of US $8.5 billion. This plant has a large generating capacity producing 3,568 MW, which can provide power to more than 45 million people, and reduces 5,146,403 tons per year of CO2 emissions. It also has a high-energy intensity of about 9 MW/km2. One of the main sustainability highlights of this project is generating energy by utilizing the high volume flow of the Madeira River, while having a reduced reservoir and low waterfall. The typology of this hydroelectric is "run-of-river" with 50 bulb-type generating units, first of its kind at this large scale, which helps to reduce significantly the area of the reservoir to 421 km2 from which 142 km2 correspond to the natural river channel. This plant is part of the first projects that have been implemented as part of the Growth Acceleration Program (PAC) from the Brazilian Federal Government. The goal of the PAC is to develop northern Brazil by contributing to energy security, job creation, and commercial activity.

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The Madeira hydroelectric plant has larger scale impacts than the Jari hydroelectric plant. It required flooding an area of about 270km² along the river channel, which affected the existing habitat along the river, subsistence agriculture areas, fish habitat, eliminated waterfalls, and displaced hundreds of families living on the river edges.

Figure 7. Jari River in 2009, the Santo Antonio waterfalls located at top center, Laranjal do Jari is about 26 km downstream, bottom center. Source: Google Earth Pro, 2018.
The Santo Antonio hydroelectric plant located in the Jari River produces 373.4 MW, which is the equivalent of providing power to 3 million inhabitants and reducing 352,648 tons of CO2 emissions per year. This plant represents a $360 million USD investment and is operating since 2014. The typology is considered platform hydropower consisting of a 31.7 km reservoir, 3 Francis-type generating units with an installed capacity of 370
MW and one Bulb-type generating unit with an installed capacity of 3.4 MW. The construction of the reservoir flooded an area of 31.7 km² in the Jari River displacing families living along the river, flooding subsistence agriculture areas, changing fish habitat, and reducing significantly the waterfalls. According to the environmental licenses there is a program for the recovery of degraded areas to offset the 1,706 hectares of native forest habitat suppressed for the creation of the new lake reservoir. The economic activity from the relocated communities relies on gathering Brazil nuts in the forest, açai berries, and fishing. In terms of impact, the Jari hydroelectric plant relocated completely Vila Sao Francisco Iratapuru, and created about 1800 jobs in its construction peak from which they recruited workers in Laranjal do Jari, Vitória do Jari, and Almeirim municipalities. In the Jari River Basin the population has been increasing, between 2000 and 2010, the municipality of Laranjal do Jari grew by 40.07% and Vitória do Jari grew by 45.18%.\(^{11}\) The plant is connected to the national grid, which enables the energy produced at Jari hydroelectric to be used at industrial complexes downstream, and in large cities. The renewable energy influx contributes to reduce carbon emissions and to increase the reliability of energy supply in the region.

**Methodology**

The methodology used for finding the main sustainability challenges is based on case studies assessments\(^{12}\) following the Envision\(^{®}\) rating system criteria, and field research that included workshops with public officials, interviews with stakeholders, site visits, GIS mapping, site surveying using drone imagery, and seminars in local universities.

Envision is a tool designed to measure the sustainability of infrastructure, which includes resilience as a key consideration. The framework of Envision version 2 was used in the assessments. The Envision sustainability criteria is allocated in 60 credits divided into 5 categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk. In general, the sustainability criteria looks at how projects reduce risks to the community, and the environment, which is assessed according to project efforts spent in improving quality of life, planning for short- and long-term hazards, safeguarding resources, reducing emissions, and avoiding or mitigating environmental impacts.

The field research included site visits to the hydropower locations in the Jari River and the Madeira River. In both locations stakeholder engagement was made through meetings with developers and operators of the hydroelectric plants, affected communities, municipalities, environmental regulators, local non-profit foundations, and farmer cooperatives.


\(^{12}\) The Envision assessments are part of case studies from the Infrastructure 360° initiative at the Harvard Zofnass Program for Sustainable Infrastructure in collaboration with the Inter-American Development Bank to evaluate sustainable practices in infrastructure development.
As part of the fieldwork, mapping and site surveying contributed to the findings of the research. The mapping has been made using GIS data and drone imagery captured at location looking at relocated communities.

In addition to the fieldwork, seminars and workshops were held in Brazil with environmental regulators, including IBAMA\textsuperscript{13}, and academics the University of Sao Paulo, the University of Brasilia, the Federal University of Amapa, and the Federal University of Pernambuco.

**Challenges in the sustainability of hydroelectric projects**

The following section presents the sustainability challenges from each hydroelectric plant based on sustainability assessments and field research in the Amazon. The challenges are grouped according to the Envision categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk.

**Quality of Life**
The Qualify of Life category addresses projects’ impacts to communities through three main subcategories: Purpose, Wellbeing, and Community. **Purpose** relates to how the project impacts growth, local development, and jobs creation. Both projects performed high in developing local skills and capabilities, addressing the need for renewable energy in the region, and contributing to the greening of the Brazilian energy matrix. At the peak of construction, the Madeira plant created approximately 20,000 jobs, from which 80% of the positions were filled locally. In the Jari plant, the construction peak brought 1,800 jobs where 68% were filled locally.

Population **displacement from flooding** is a major challenge and concern for both plants as it impacted many communities. In Jari 94 families have been affected, and 34 families completely displaced to an inland location upstream of the reservoir. The displacement of families entails planning efforts to ensure that the quality of life can be improved. The **impact to the livelihoods of displaced families** must also be evaluated; in this case it mostly consists of gathering Brazil nuts in the forest and selling to distributors. Input from field research at Jari revealed that the areas where the families were relocated, are closer to the forest areas with brazil nut trees, but are isolated and far from the urbanized areas. In terms of local development, a Brazil nut processing center was improved for the nut gatherers cooperative, but it was out of operation during the site visit due to fire that destroyed the facility. This isolation makes difficult the families to access jobs, schools, and many other resources. To meet this need, an elementary school was built at the location where teachers stay about 3 months at a time due to the remote location. The site visits and surveying using a drone revealed that informal settlements are expanding in each of the affected and relocated communities. According to the community leaders, families are building houses for extended family members, as they prefer to stay together and avoid crime locations, which are threats present in the Laranjal do Jari. In the Madeira plant, the flooding displaced riverfront communities of about 540 families, which received compensations and new housing. According to the project team, the compensations and resettlement conditions were discussed with all the people affected by the project.

\textsuperscript{13} Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA).
Another regional challenge is a general **lack of infrastructure basic services**, such as potable water, electricity, and sanitation, which is a significant barrier for sustainable growth in the Amazon. In both cases the relocation from the low-lying areas to higher inland areas needs a long-term vision, as basic infrastructure services continue to be limited in both areas. In Brazil having access to electricity is considered a citizen right, and the government is implementing access mostly through grid expansions from the program *Luz Para Todos* (Light for All). In the Amazon, the grid expansion model is not a cost-effective measure in remote locations. The high costs of expanding the SIN to reach low-income communities located at the end-of-the-line has made off-grid energy systems common solutions to energy access. Diesel fueled generators continue to be one of the main energy sources for these communities, which in this case are living close to a hydropower plant.

In the Jari plant area, the affected communities complained about having neither electricity nor access to the national grid where the power from the hydroelectric plants goes. In the pre-development context, these communities already lagged behind in terms of access to basic infrastructure services, but had limited access to diesel-operated generators subsidized by *Luz Para Todos*. With the arrival of hydropower development to the area the government eliminated the support of diesel systems and fuel allocations since solar microgrids were installed through the donation of the project developer. The capacities of the systems were under designed and the solar microgrids collapsed to the growing energy demand of the communities and the lack of maintenance. Planning microgrids for medium or long term has been a difficult process in Brazil as the demand projection of off-grid systems is hard to predict, especially in communities that are expanding. Following pressure from the communities and the Municipality of Laranjal do Jari, multiple public meetings were held to plan and resolve the lack of access to electricity. In 2017 the Amapá state government announced a resolution from these meetings, replacing 2 solar microgrids with a grid extension in two communities, and upgrading and expanding the solar capacity in the third community. The sustainability of solar microgrid systems is linked to community buy-in and should be planned with their goals in mind, as these determine the size, cost, and configuration of the system, as well as how to balance the energy supply and demand.

In terms of potable water systems, in the Jari area water tanks were installed in the affected communities. In the Madeira plant, during meetings with the Municipality of Porto Velho, the communities complained about the newly built potable water and septic systems, which in some cases the wastewater contaminated the potable groundwater systems due to **higher water table levels**, which is an impact that was not considered a risk when the relocated community water systems were planned. The Porto Velho area is highly urbanized, and connections to the electrical grid are easier to obtain.

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15 EDP Energias do Brasil is the private developer and operator of the Santo Antonio do Jari hydroelectric plant in the Amazon.
16 According to site visits and meetings with the community leaders in April, 2017.
17 Findings from Empresa de Pesquisa Energética (EPE), Brazilian Energy Research Company in charge of identify the most appropriate alternative for energy expansion from the technical, economic and socio-environmental points of view http://epe.gov.br
18 According to site visits and meetings with the municipality and community in April, 2017.
The **Wellbeing** subcategory represents an area that is a challenge for both plants. It looks at how infrastructure projects improve comfort, public health and mobility of the surrounding communities. The Madeira plant "run-of-the-river" approach to public health and safety met the criteria as it was able to show measurable results against **vector-borne diseases** that are safety threats associated with water held in reservoirs. As the Jari plant has a contained reservoir, the project developed a health program to control vectors, monitor epidemiological threats, and provide health education.

Both projects reduced noise and vibrations during construction, but there are any assessments of noise and vibrations during operations, which is an aspect that could be improved in the environmental licensing process of a hydroelectric plant. No consideration was taken in minimizing light pollution at project level or looked at environmental regulations, at neither the Madeira plant nor the Jari plant.

In improving community **mobility and access**, the Madeira hydroelectric performed better by supporting and investing in the Urban Mobility Plan of Porto Velho. The urban location surrounding the hydroelectric is an advantage, but it is not clear how this plan supports the mobility of the community or alternative modes of transportation such as biking or walking. In the Jari plant, alternative modes of transportation are not feasible options due to the long distances and remoteness; in this area motorized transport by boat or jeep is necessary. The distances from the project, or from the affected and displaced communities to nearest urban area in Laranjal do Jari are approximately 40 km. The roads are generally unpaved and in rough terrain, making motorized boats a preferred option. During construction the mobility of workers was supported to and from the construction site.

The **Community** subcategory is about ensuring that the project uses context-sensitive design that respects maintains or improves its surroundings. Both projects are in compliance with Brazilian regulations and took steps to identify, preserve or restore cultural resources related to the archaeological, prehistoric and historic heritage of the area. In the Madeira plant location, 58 archaeological sites were found, as well as Paleo botanical fossils that have been preserved for further studies.

**Preserving views and local character** is a challenge for hydroelectric plants due to the landscape modification that these require. In Jari River, the Santo Antônio waterfalls, considered a regional natural heritage site, were partly preserved by relocating the dam upstream from the falls, as well as concentrating temporary and permanent construction on the right bank of the river. In addition the height of the dam was modified to preserve the necessary flow for the waterfall. This effort helped preserve a considerable section of the waterfalls. In the Madeira location, the preservation of two culturally important waterfalls, the Santo Antônio and Teotônio was not possible. The waterfalls were submerged in water due to the construction and operation of the plant, which also displaced the communities neighboring the waterfalls. In addition, the upper Madeira River with 18 waterfalls locations has been visually impacted as waterfalls are submerged by water.
The Madeira plant improved existing public spaces, as it created parks, an artificial beach, a soccer field, an Indigenous cultural center, and wildlife viewing areas. Important tourist sites were restored, such like the surroundings of the Santo Antonio chapel, and the Madeira Mamoré Railway Complex. In Jari, the relocation of the community Vila Iratapuru included a soccer field, a covered sports center and a public square.

**Leadership**

Leadership addressed project team communication and collaboration strategies for achieving sustainable performance. Stakeholder engagement is an important component for a holistic, long-term view of the project's life cycle. The goals of this category are divided in three sub-categories: Collaboration, Management, and Planning.

**Collaboration and stakeholder engagement** are challenges for hydropower plants in assuring meaningful participation by integrating more the communities' input during the project's decision-making process. In Madeira there were efforts to identify key stakeholders and establish communication according to the federal environmental permitting regulations. The participatory process had more than 2000 people in meetings and public hearings.

According to the Laranjal do Jari Municipality, the participatory process for the implementation of the plant was limited and not clear for the affected communities, which complained about impacts well after the construction of the project.

In the Madeira plant, the Equator Principles were adopted as a way to implement leadership and commitment to improve sustainable performance. A project adopting the Equator Principles should propose measures to minimize, mitigate, and offset adverse
impacts appropriately according to the nature and scale of the project. For the Jari plant, in terms commitments, the project team developed a series of policies addressing ethics, sustainability, commitment to stakeholders, environment, health, and safety, social investment, anti corruption, biodiversity, among others.

The improvement of infrastructure integration is a challenge for this type of large-scale project. In Jari there were some improvements, but more integration is needed in the provision of basic infrastructure services in the area. In terms of national integration both hydroelectric plants are connected to the National Interconnected System,\textsuperscript{19} the electric grid.

In Planning having a long-term view is encouraged for the sustainability of a project. For both projects planning and identifying resources for long term monitoring and maintenance beyond the concession period is a challenge. Planning for the affected communities should be for the long term and in collaboration with government authorities. During field research and engagement with stakeholders, many of the preexisting needs remained unmet, such as lack of electricity, potable water, and sanitation. Basic infrastructure services are usually addressed by government agencies. In both locations there was expectation from the affected communities and the municipalities to have the hydropower developer address the needs. While this might be cost prohibitive for a project, addressing these needs in collaboration with the government is an opportunity to improve the sustainability of the project.

Resource Allocation
Resource allocation addresses the use of materials, energy, and water requirements during the construction and operation of infrastructure. Projects should choose less toxic materials and promote renewable energy resources. Materials, Energy, and Water are the subcategories.

In terms of minimizing the use of resources, both plants need to identify and reduce the use of materials. The net embodied energy of both plants is unknown; a lifecycle assessment should be integrated in the planning of these projects in order to reduce embodied energy and enhance the sustainability.

The sourcing of materials is another challenge for these large scale projects. In the Jari plant, some savings in the use of materials were achieved as the main materials such as rocks, sands and clay used were locally sourced. In the Madeira plant a basic sustainable sourcing has been followed, but the tracking and monitoring suppliers is lacking. It is important for this type of projects to make inventories of materials use in order to set reduction targets. According to the project team materials were sourced locally in the region, but without an inventory it is difficult to know to what extent regional materials were used. In Jari about 25\% of all the waste generated has been either recycled or reused. In Jari, also, the excavated material remained on site.

In the Madeira location there is a lack of public waste infrastructure management. A management plan that can include community waste and continue beyond the construction period will be valuable. According to the team most of the excavated

\textsuperscript{19} Brazilian national grid or Sistema Interligado Nacional, SIN.
material was reused on site.

On the **use of Energy**, both projects were not aware of the potential to reduce energy consumption in the plant. A suite of feasibility studies and cost analyses are needed for both projects in order to determine energy consumption and be able to set reduction targets. On **renewable energy generation**, both projects performed exceptionally high as the Jari produces 373.4 MW, and Madeira 3,568 MW. In addition, in Jari various renewable energy sources were installed in the affected communities, but the solar systems were under designed and not maintained.

On the **use of Water**, an overall reduction on water use is desired. In Madeira the fresh water available is supported by the typology of the project, "run-of-the-river" which allows water to flow through. In Porto Velho, potable water supply coverage is 30.6% while the national average is 90%. Outside the urban areas, there are wells of about 10-15 meters deep, known as ponds wells or Amazonian wells as these are popularly known. Sewage discharge in relocated communities goes into septic tanks or into the Madeira River as there are no treatment facilities available.

In Jari, there are no references about the reuse of gray water, nor strategies for **reduction of potable water consumption**. There are internal water monitoring programs in the river according to the required programs as established by the licensing of the project. In both projects, more efforts are needed in the **commission and monitoring of energy and water systems** by third parties.

**Natural World**
The Natural World category is about avoiding and minimizing negative environmental impacts. It looks at the siting of a project, as well as impacts to water and land, and biodiversity.

The **siting of hydroelectric projects** in the Amazon is a big challenge as these locations are considered greenfields of high ecological value that require cutting down native forest areas. In Jari **1,706 hectares of native forest** were cut down and in Madeira **10,448 hectares of rainforest** and low alluvial lands were cut down. The licensing process establishes compensation methods for the recovery of degraded areas. The development in both rivers was not avoided, although some actions were implemented to mitigate the impact and to document the biodiversity of the flora and fauna. In this regard, the Madeira project started various programs to study the biodiversity of fish, and plants. Many new species were found from this effort.

In **Land and Water**, wetlands and surface water areas were not preserved in both locations due to hydroelectric plants impact. In Jari efforts were made to have all temporary and permanent structures were concentrated on the right bank of the river, an area already disturbed by anthropogenic activity. This action helped avoid disruption of the left bank that contains areas of native forest. In the Madeira the topography was modified to accommodate the water level to 70.5m to create the reservoir with a maximum level of 71.31 m.

In Jari **adverse geology** was avoided by constructing on the massif that showed good geological conditions. The Madeira River, according to the documentation avoided adverse geology by taking advantage of the rocky outcrops of the Sao Antonio
waterfalls. During field research the municipality expressed various erosion concerns on the riverbanks.

Both projects developed programs to recover degraded areas in order to preserve the biodiversity, and improve floodway functions. In Jari, an effort was made to restore vegetation with native species that help preserve conditions of infiltration and evapotranspiration.

In terms of storm water management, the Madeira plant modified the topography, which changed the average annual river runoff predevelopment volume. According to the environmental licensing, the project set various monitoring programs that look at sediments, biochemicals, limnology, and aquatic macrophytes.

Biodiversity protection is a challenge for these large-scale projects located in areas of high biodiversity, most of the efforts of both projects in this area are in preservation and habitats restoration requirements. In the Madeira plant nurseries were established to be able to supply locally appropriate plant material. In addition a fauna rescue center was built to return animals to the wild when possible.

At Jari hydroelectric plant, an environmental buffer zone of 100 meters was established around the reservoir. This plant has contributed to controlling invasive species by using only native vegetation. In the Madeira plant a buffer area of 1,987 hectares around the reservoir was created with widths that range from 500 to 30 meters in the urban areas. The Madeira plant also instituted innovative approaches to preservation that included the publication of books with the newly identified 459 fish species, 65 of amphibians and 45 reptiles. Also 24 possible new species of amphibians might have been discovered. In order to protect the large amount of fish species, a fish ladder was designed to recreate the conditions of the waterfall that existed previous to the plant.

Climate and Risk
This category addresses emissions, increased short and long-term risks, as well as resilience towards short-term hazards or long-term altered future conditions. The two subcategories are Emissions and Resilience.

Emissions represent efforts in reducing greenhouse and pollutant gas emissions, as well as other dangerous pollutants during all stages of a project’s life cycle. Both projects performed well in reducing emissions due to the fact that these are clean development mechanisms that produce renewable energy which displace CO2 emissions from fossil fuels. The Madeira plant produces energy at an intensity of about 9 MW/km², this is double the minimum energy efficiency for carbon credits generation. As a Clean Development Mechanism (CDM), the reductions are 5,146,403 tons per year. For Jari, the reduction has been estimated at 352,648 tons of CO2 equivalent per year. In terms of other pollutant emissions reduction, renewable energy is helping replace the local and regional fossil fueled energy systems.

Resilience is one of the areas that present the most challenges. For both projects there is a lack of comprehensive climate impact assessment and/or adaptation plan
developed for long-term risks. Knowing what are the types of risks and probability of risks would allow project teams to anticipate, withstand, or adapt to these risks, which would minimize its overall vulnerability. Unpredictable river flow variations or a drought that affects energy generation can be some of the threats associated with these projects. The project teams are dealing with short-term hazards better. Both plants had plans on how to deal with these natural and man-made hazards, such as such as floods and earthquakes. Although both projects have plans on short-term hazards, **flooding** continues to be a concern in both locations as more frequent and destructive floods are occurring in these locations. Not having a plan to face **climate change threats** puts both hydroelectric projects and communities in disadvantage.

**Conclusions**

The overview of challenges in the hydropower development in the Santo Antonio plants located Jari River and the Madeira River present lessons learned and opportunities for improvement in the planning, design, and implementation of future hydroelectric projects. Both plants contribute significantly to the greening the Brazilian energy matrix by generating large amounts of renewable energy totaling to about 3941.4 MW, and mitigating large amounts of CO2 emissions, together totaling 5,499,051 tons per year. Further work is needed in narrowing the infrastructure gap on areas surrounding this type of projects, and in increasing the contribution to the sustainability targets delineated in the UN Sustainable Development Goals (SDGs).

Both projects faced similar challenges, as seen highlighted in red in figure 11, and concerning impacts to the quality of life, governance, use of resources, environment, and climate risks. The results of the analysis highlight the areas that require more careful attention when planning or implementing a project. The main social and environmental challenges are related to the impacts surrounding the implementation of the reservoirs, dams, and the preexisting lack of basic infrastructure services.

The challenges in meeting the sustainability criteria can be summarized the following topics: community, wellbeing, collaboration, management, and planning, use of materials, energy use, water use, siting, land and water, and resilience. The main challenges are organized according to the Envision categories: 1) Quality of Life, 2) Leadership, 3) Resource Allocation, 4) Natural World, 5) Climate and Risk.

1) The challenges related to quality of life impacts include population displacement from flooding, impact to livelihoods, risks of vector-borne diseases, preserving views and waterfalls.
2) Among the challenges related to leadership and governance are engaging stakeholders effectively, collaborating with local authorities and municipalities, integrating infrastructure, and investing in long-term planning.
3) The challenges surrounding the use and allocation of resources are calculating net embodied energy, sustainable sourcing of materials, reducing energy and potable water consumption.
4) The natural world challenges are related to the environment and location of these projects, which include building on greenfields of high ecological value, reducing the cutting down of native rainforest, reducing erosion risks, recovering degraded areas, restoring habitat, managing storm water, higher water table levels, and sewage
discharges, establishing buffer zones using native species, rescuing wild animals, and restoring fish habitat.  
5) Challenges related to climate change risk are assessing and developing awareness of climate change threats, planning for adaptation to long-term risks and potential altered future conditions.

Following the sustainability and resilience holistic framework from the Envision rating system, as well as reviewing the findings on the challenges surrounding these two hydropower projects can help guide future development towards sustainability and resilience in the Amazon.


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