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ENVIRONMENTAL IMPACTS OF HYDROELECTRIC CONSTRUCTION: COMPARATIVE ANALYSIS OF ADA KALEH AND BELO MONTE

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Abstract: *The construction industry plays a central role in national development, yet it remains a major contributor to global environmental degradation. This study addresses the critical issue of sustainability in large-scale hydroelectric construction by examining two emblematic cases: Ada Kaleh (Romania) and Belo Monte (Brazil). Using a qualitative, document-based methodology, the research analyzes the socio-environmental consequences of these projects, including habitat destruction, community displacement, and cultural loss. The findings reveal that both developments, despite differing in scale and context, resulted in similar patterns of irreversible ecological damage and inadequate mitigation efforts. The study concludes that more integrative planning, participatory governance, and sustainability-oriented strategies are essential to balancing infrastructure development with environmental and cultural preservation.*

Key words: *construction, environmental impacts, sustainability, Ada Kaleh, Belo Monte.*

1. Introduction

Urban expansion has significantly amplified the environmental pressures linked to construction activities. As one of the most resource-intensive sectors, the construction industry is responsible for a substantial share of negative anthropogenic impacts, including high energy and raw material consumption, significant greenhouse gas emissions, and the transformation of natural and urban landscapes. Such activities alter ecosystems, deplete natural resources, generate substantial waste, and create tensions between development goals and environmental conservation.

The implementation of new construction projects, driven by demographic growth and urbanization, produces wide-ranging impacts across environmental, social, and economic spheres. These effects may vary in scale and intensity, influencing everything from local neighbourhoods to entire cities. Construction projects can bring both benefits and inconveniences, directly affecting the environment, society, and the economy. For

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example, interventions such as large-scale hydroelectric developments often result in the alteration or destruction of ecosystems, flooding of extensive areas, degradation of vegetation, soil sealing, increased noise and congestion, and substantial waste generation.

Despite its essential role in providing infrastructure for housing, transportation, health, and education, the construction sector remains a major contributor to global environmental degradation. The extraction of raw materials, such as sand, stone, and wood, and the subsequent disposal of construction waste, exacerbate ecosystem degradation and unsustainable resource use. These impacts underscore the urgent need for the adoption of sustainable practices and technologies within the industry, especially considering growing concerns over climate change and resource scarcity.

This paper examines the environmental impacts of the construction industry, with a particular focus on the socio-environmental consequences of large-scale hydroelectric projects. By analysing the cases of Ada Kaleh and Belo Monte, the study highlights the sector's influence on population displacement, loss of cultural heritage, and ecological degradation. The aim is to identify effective strategies for integrating sustainability into construction planning, execution, and management, thereby promoting a balance between economic development and environmental preservation.

2. Methods

This study employs a qualitative research methodology (see Figure 1) based on documentary analysis to investigate the environmental impacts of the construction industry, with a particular focus on the cases of Ada Kaleh and Belo Monte. The approach is structured to provide a comprehensive understanding of both theoretical and practical aspects of construction's environmental effects.

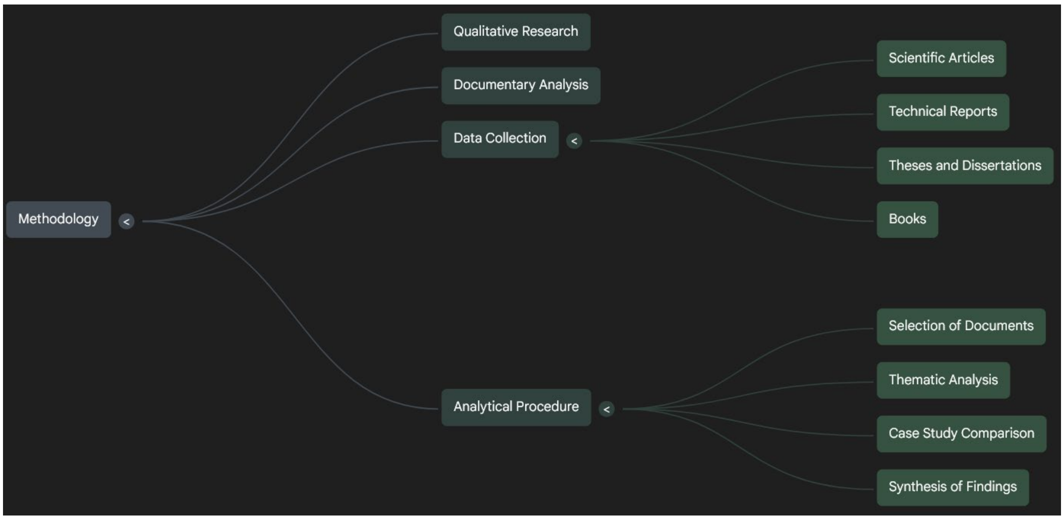

Fig. 1. *Methodology*

Data Collection:

- Scientific articles: Peer-reviewed journal articles addressing sustainability, environmental impacts, and construction practices.
- Technical reports: Official documents and environmental impact assessments related to large-scale construction projects.
- Theses and dissertations: Academic works that provide in-depth case studies and theoretical frameworks.
- Books: Authoritative texts on sustainable construction, environmental management, and civil engineering.

Analytical Procedure:

- Selection of Documents: Sources were chosen based on their relevance to the research objectives, credibility, and coverage of both global and case-specific issues.
- Thematic Analysis: Documents were systematically reviewed to identify recurring themes, such as resource consumption, waste generation, greenhouse gas emissions, and socio-environmental impacts.
- Case Study Comparison: The environmental, social, and cultural impacts of the Ada Kaleh and Belo Monte hydroelectric projects were analyzed in detail, using both primary and secondary sources.
- Synthesis of Findings: Insights from the literature and case studies were integrated to highlight challenges, best practices, and lessons learned in sustainable construction.

This qualitative, documentary approach enables a nuanced understanding of the complex interactions between construction activities and environmental outcomes, ensuring that the analysis is grounded in both empirical evidence and established theory.

3. Results and Discussions

3.1. Environmental Impacts of the Construction Sector

The construction sector is identified as one of the major worldwide contributors to environmental deterioration, with its effects beginning right from the extraction of raw materials and extending using resources and permanent ecological alterations at building sites. Construction operations are responsible for nearly half of the total solid waste generation, 20% to 50% of natural resource consumption, and roughly half of the world's carbon dioxide emissions. Most of this waste occurs in the operational phase, hence playing a great role in air, soil, and water pollution. These findings align with global research identifying core environmental impacts as excessive resource and energy consumption, waste generation, pollutant emissions, and biodiversity loss (see Figure 2).

3.2. Sustainability in Construction

In recent years, there has been increased incorporation of sustainable measures in the construction sector, fuelled by the pressing requirement to minimize environmental effects and enhance the efficiency of resource utilization. Some of the main sustainable strategies entail the exploitation of renewable resources, enhancing waste management practices, the use of green building technologies, and applying circular economy principles. However, the sector faces significant challenges (see Figure 3), such as the high cost of sustainable materials and technologies and limited technical expertise among construction professionals. Despite these challenges, there is growing awareness and readiness on the part of building professionals to engage in more sustainable practices.

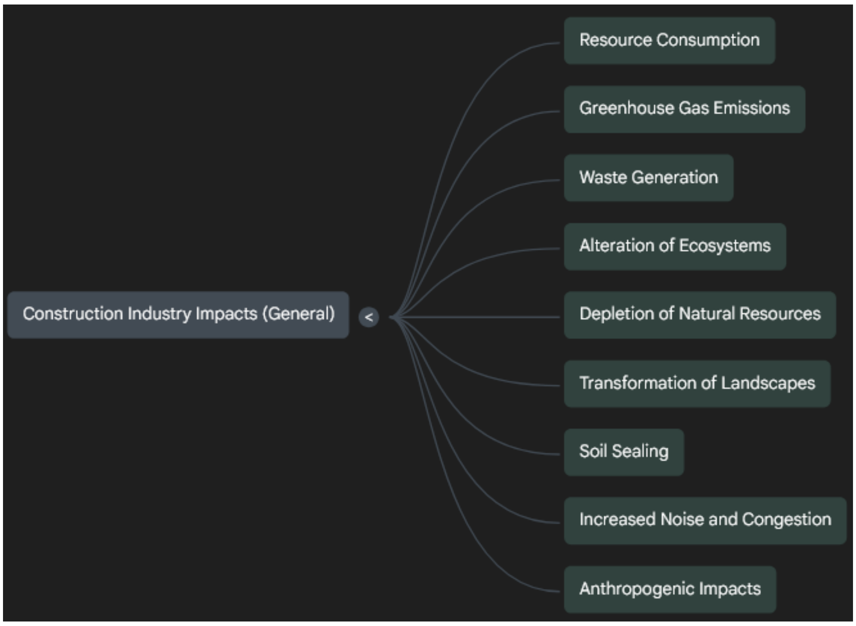

Fig. 2. *General Construction Industry Impact*

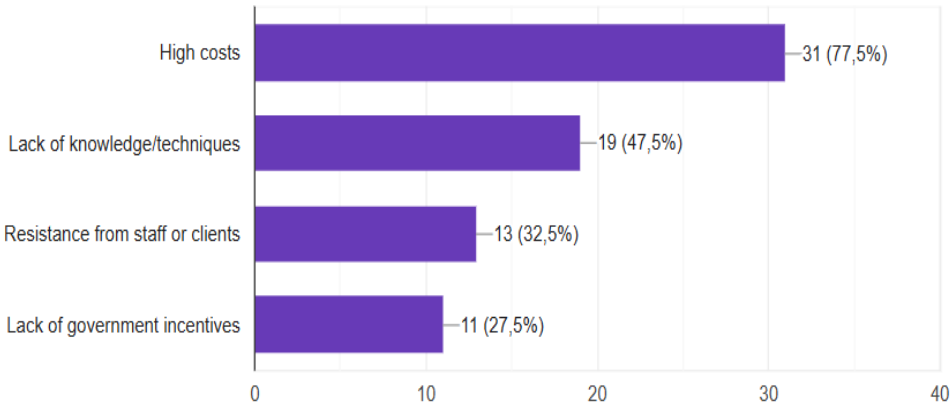

Fig. 1. *Challenges to implement sustainability*.

The construction industry has therefore adopted a series of innovative approaches to reduce its environmental impact:

- Sustainable buildings: These projects use materials with a low environmental impact and techniques that reduce energy consumption. Elements such as green roofs, rainwater harvesting systems and better thermal insulation are common, with the aim of reducing the carbon footprint.

- Smart technologies: tools such as BIM (Building Information Modelling), a 3D modelling software that allows professionals to bring together all the components from all suppliers in one place, facilitating decision-making and cost reduction. BIM allows detailed visualisation of projects at all stages, making it easier to identify problems before construction begins, which helps to avoid waste and minimise environmental impacts.
- Modular construction: as well as reducing material waste, modular construction cuts construction time by up to 50 % compared to traditional methods. It also reduces pollutant emissions at the building site due to the shorter time spent on site.
- 3D printing: this technology makes it possible to build complex shapes that would be difficult or impossible to reproduce using traditional techniques. It uses less material and can incorporate recyclable materials directly into the printing mixtures, increasing sustainability.
- Use of ecological materials: this includes bricks made from recycled material, insulation panels made from natural fibres, and the use of permeable concrete for better rainwater management.

3.3. Waste Management

Raw Material Depletion, production costs, performance, Scalability, and Environmental Impact, while some of the benefits that come from true zero carbon cement Reduced CO 2 emissions, Less Energy consumption, fewer raw materials, Potential for lower cost, Equivalent performance, Scalable production, And reduced environmental impact, By recycling of waste, it helps save limited landfill space saves waste disposal costs, reduces the demand for natural resources and minimizes concrete waste (see Figure 4). The amount of energy needed for the recycling of such recyclable material for use in manufacturing is lower than for raw materials. The most promising possibility seems to be the use of the recycled material in construction [1].

Table 1

Classification of solid waste [11]

Class	Condition
I	Dangerous
II	Not dangerous
IIA	Not dangerous and not inherent
IIB	Not dangerous and inherent

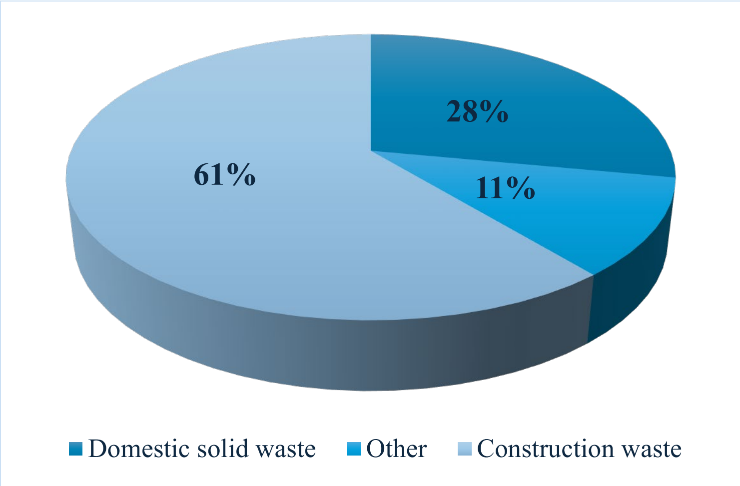

Fig. 2. *Percentage by mass of the various constituents of municipal solid.*

Table 2

Characteristics and recommended use of recycled aggregates [2]

Product	Characteristics	Recommended use
Recycled sand	Recycled concrete and concrete blocks yield material devoid of impurities and with a maximum characteristic size of under 4.8 mm.	Mortar for installing sealing masonry, screed, soil-cement, sealing bricks and blocks.
Recycled stone	Recycled concrete and concrete block material that is free of impurities and has a maximum characteristic size of 6.3 mm.	The production of concrete items like drainpipes, interlocking floors, sealing blocks, and others.
Recycled crushed stone	Recycled concrete and concrete block material that is free of contaminants and has a maximum characteristic size of less than 39 mm.	Manufacture of non-structural concrete and drainage works
Running spout	Impurity-free materials obtained from the recycling of construction waste (such as ceramic remnants, concrete blocks, etc.) with a maximum typical size of 63 mm.	Base and sub-base works for paving, reinforcement and subgrade of pavements, as well as regularisation of unpaved roads, embankments and topographic levelling of land
Crack	Recycled concrete and concrete block material that is clean and has a maximum characteristic size of under 150 mm.	Paving, drainage and earthworks

3.4. Hydroelectric Construction

It refers to the process of building infrastructure that harnesses the energy of moving water to generate electricity. This typically involves several key components:

- Dams: Large, man-made structures built to hold back water and create reservoirs. Dams raise the water level, storing potential energy that can later be converted into electricity. Dam construction is a complex, labor-intensive process involving water diversion, foundational reinforcement, and the use of structural supports like rebar and rock bolts to ensure long-term stability.
- Reservoirs: These are water storage facilities created by the dam. They store large volumes of water at an elevated height, providing the potential energy needed for electricity generation.
- Powerhouses: These buildings house the turbines and generators. Water from the reservoir is channeled through pipes (penstocks) to the turbines. As water flows down, its potential energy is converted into kinetic energy, spinning the turbines. The turbines then drive generators that convert mechanical energy into electricity.
- Hydraulic Circuits: These are systems of pipes and channels that guide water from the reservoir to the turbines and then release it back into the river after energy extraction.

The construction process involves multiple engineering specialties:

- Geologists assess the suitability and stability of the site.
- Hydrologists analyze water flow and availability.
- Dam engineers design and oversee dam construction.
- Electricians design and install the electrical systems and generators.

Hydroelectric construction can range from massive projects, such as large dams and power stations, to smaller-scale systems like micro-hydro or run-of-river setups that don't require large reservoirs. The overall goal is to efficiently convert the energy of flowing or falling water into reliable, renewable electricity.

3.5. Case Studies: Ada Kaleh and Belo Monte

The building of the Iron Gate hydroelectric dam in the late 1960s led to the submersion of Ada Kaleh Island and consequently to the total displacement of its Turkish inhabitants and annihilation of irreplaceable cultural heritage. The effect on the environment involved the flooding of extensive territories, devastation of local ecosystems, and permanent alteration of the topography of the Danube River. The project resulted in the displacement of a centuries-old community and the irreversible loss of its cultural and architectural heritage.

Ada Kaleh is an island in the Danube River, at the frontier between Romania and Yugoslavia, nowadays Serbia. It was a place of a unique Turkish community that lived there for centuries, enjoying a privileged position within the Ottoman Empire and later in the Romanian and Yugoslav states. Ada Kaleh was famous for its mosques, cultural heritage and trade, tobacco, and tourist economy.

The Ada Kaleh Island (see Figure 5) was a popular spot for local tourists with its more affordable, tax-free Turkish delights, jewelry, and cigarettes. The island was also famously known for rose and rose oil and perfume production. The museum says the island was 200 meters in length, narrow and covered in olive trees and wild vines. The earliest documentary record is found in a report prepared by the Teutonic Knights and dated 22 February 1430, which describes Banat fortresses, among them the island of Saan, which had 216 inhabitants. From 1430 onward, this place was referred to as Ada Kaleh. Strategically located, Ada Kaleh was of the greatest significance in the then-existing conflict between the Habsburg Empire and the Ottoman Empire. In 1689, the forces of Austria constructed a fortress against the Ottoman Empire. Over the next decades, control of Ada Kaleh went back and forth between the Ottoman Empire and Austria. After the Peace Treaty of Belgrade in 1739, the island remained permanently Turkish, temporarily interrupted briefly on behalf of the Austrians from 1789 to 1791. Overlooked during the Berlin Peace Congress 1878, Ada Kaleh remained a Turkish possession under Austro-Hungarian rule until 1918/1920, when it became officially part of Romania. Most inhabitants on the island were Turkish. Prior to the construction of the Iron Gates dam (Figure 5), the main historic buildings on the island were demolished. The effort to reconstruct them at a downstream location on Șimian Island in subsequent years was unsuccessful, however, since most residents preferred to relocate to other areas in Romania or emigrate to Turkey [7].

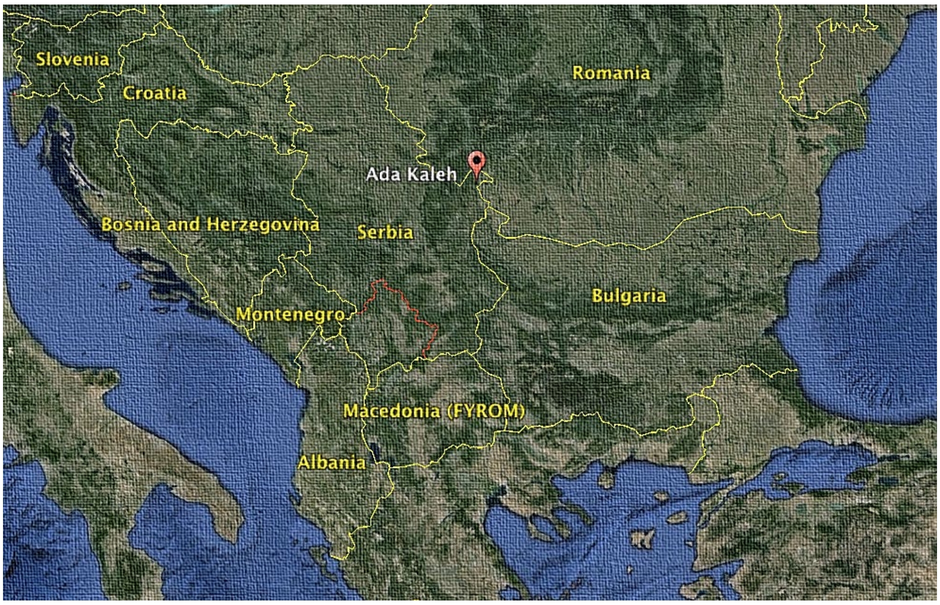

Fig. 3. *Ada Kaleh Island location*

The topographical features of the area made it impossible for tugboats to travel upstream. The building of the iron dam was not only directed towards improving navigation on the Danube by eliminating sediment and sand obstructions at the mouth of the river but also towards supporting hydroelectric plans to irrigate about 1.2 million hectares of arable land through the creation of reservoirs. The laying of the foundation stone of the hydroelectric power plant took place symbolically on September 7, 1964. More than 20,000 people were involved in building the dam, locks, power stations, and reservoir. The installation of the iron gate (see Figure 6) system led to the permanent diversion of the course of historic settlements located along the shores of the Danube. In the 1960s, the island of Ada Kaleh, which was situated close to Orșova and Drobeta

Turnu-Severin and settled since ancient times, was covered by the newly formed reservoir. However, the evacuation was spread wider than Ada Kaleh, affecting thousands of inhabitants of the municipalities of Orșova, Eșelnița, Dubova, Vârciorova, Tufări, Jupalnic, Ogradena, Tișovița, and Plavișevița; these Romanian municipalities were flooded by the Danube's rising waters. The evacuation took place in the town of Orșova in Mehedinți starting in the mid-1960s, when the population was about 5,000 inhabitants. Most of them were resettled to a new-built town of Orșova located on the shores of the Danube, approximately three kilometers from the old town center, between 1966 and 1971 [4].

Fig. 4. *Iron gate hydroelectric power station in Ada Kaleh*

The Belo Monte hydroelectric project, one of the largest globally, has triggered profound environmental and socio-cultural consequences. The construction of the dam has led to the displacement of over 40,000 people, including indigenous people and riverbank dwellers, alongside rampant deforestation and drastic biodiversity depletion in the Amazonian environment. In addition, the project has been associated with increased greenhouse gas emissions from the reservoir, as well as ongoing controversies regarding land and resource rights. Despite the implementation of mitigation strategies, numerous environmental and social impacts remain insufficiently resolved.

The Belo Monte hydroelectric power plant, located on the Xingu River in the Pará state of Brazil, is one of Latin America's most important electricity generation projects. With an estimated installed capacity of more than 11,000 megawatts, the project was designed as a key response to the growing energy demands in Brazil. However, since the inception of its planning, Belo Monte has been subject to intense scrutiny and opposition due to its vast environmental, social, and cultural implications.

The construction started in 2011 after long legal battles and intense campaigning by indigenous groups, environmentalists, and social movements. The affected area has a large percentage of Brazil's extensive biodiversity and is the ancestral home of many indigenous groups and riverside peoples. The construction of the dam flooded around 516 square kilometers, resulting in huge alterations in the Xingu River and having negative impacts on the livelihoods of thousands of people.

The project rationale lies in the need to increase energy production, in consideration of the projected economic growth of the nation within the coming years. In consideration of this, the electricity generated by the Belo Monte Hydroelectric Power Plant offers a feasible solution to reinforce the energy infrastructure of regions where electrical capacity is close to its limit when connected to the National Interconnected System [5].

The Belo Monte Hydroelectric Power Station project is located on the Volta Grande do Rio Xingu in the state of Pará in north Brazil. The project involves a dam, a reservoir, a water intake facility, and a powerhouse, and therefore impacts areas in the municipalities of Altamira, Vitória do Xingu, and Brasil Novo. The hydroelectric dam directly impacts three precise locations: Sítio Belo Monte, which is located at the intersection of the Xingu River and the Transamazon Highway; Sítio Pimental, which has areas in the intermediate section between Belo and Vitória do Xingu, and Altamira; and Sítio Bela Vista, Pimental, and Monte. Based on the described project specifications, the water intake facility, the main powerhouse, and the dams built to hold the local valleys are at the location of Belo Monte. The main river dam, the main spillway, and an auxiliary powerhouse will be built at Sítio Pimental, while a second spillway next to the main spillway is planned to be at Sítio Bela Vista [5].

The Belo Monte Hydroelectric Power Plant was first proposed in the 1980 Hydroelectric Inventory Studies as a component of the Xingu River Basin project by consulting company Camargo Corrêa. Originally named Kararaô, meaning “war cry” in Kaiapó language, it was envisioned as part of a large-scale plan to build five hydroelectric plants along the Xingu River, namely Jarina, Kokraimoro, Ipixuna, Babaquara, and Kararaô. The National Electricity Plan of 1986 suggested the construction of 165 hydroelectric plants, to be finished by the year 2010, with 40 of these plants planned within the bounds of the Legal Amazon, mostly along the Xingu River. By February 1989, the project had attracted international attention and led to the Meeting of Indigenous Peoples in Altamira. The project is expected to flood two million hectares, thus impacting many Indigenous lands and riverside communities. Strong resistance was shown by Indigenous peoples, environmental groups, and social movements, which culminated at the Meeting of Indigenous Peoples in Altamira in February 1989, leading to demands for a temporary halt to the project's progress.

3.6. Comparative Analysis

Belo Monte and Ada Kaleh epitomize the complicated compromises needed to balance economic progress with environmental sustainability and social cohesion. While these projects advanced national energy infrastructure, they simultaneously caused lasting environmental degradation, cultural erasure, and social disruption. These incongruities highlight the need for detailed environmental impact analyses, active stakeholder participation, and the integration of environmental principles right from the planning phase.

Table 3

Comparison between Ada Kaleh and Belo Monte

Aspect	Ada Kaleh (Romania)	Belo Monte (Brazil)
Projects Type	Hydroelectric power station (Iron Gate I)	Hydroelectric Power station (Belo Monte)
Population	Turkish community of 600 people	Indigenous, riverside and urban communities 40,000 people
Territorial loss	Total submergence of the island	Partial flooding of the region and diversion of the river course
Environmental impacts	Submergence of river ecosystems and habitat destruction	Deforestation, alteration of the hydrological cycle, loss of biodiversity
Social impacts	Forced displacement and cultural loss	Displacement, social conflicts, pressure on public services
Mitigating measures	Limited resettlement (Simian Island)	Resettlement programmes, compensation and environmental measures
Community participation	-	Partial and highly critical of consultation with indigenous communities

A comparative examination of the impacts caused by the Ada Kaleh and Belo Monte dam projects (see Figure 7) exposes the widespread implications of large-scale hydroelectric projects. The following figure illustrates a comparative table that highlights the environmental, social, cultural, and economic impacts noted in both case studies.

Despite this, the Belo Monte and Ada Kaleh hydroelectric projects represent two significant achievements in the history of engineering in their respective historical and geographical contexts. Despite the disparity in time, cultural context, and environmental conditions, both projects reflect the far-reaching influence that large-scale infrastructure projects can have on natural ecosystems and human populations.

The construction of large hydroelectric power generation plants, while important for the development of a nation's energy sector, often involves quite significant socio-environmental impacts. The experience of the Iron Gate I hydropower project in Romania, involving flooding of Ada Kaleh Island, and that of the Belo Monte hydropower plant in Brazil show how developmental gains can occur together with negative impacts on the environment and cultural heritage. A comparison of both projects reveals similarities in their consequences despite important differences in context, political situation, and scale.

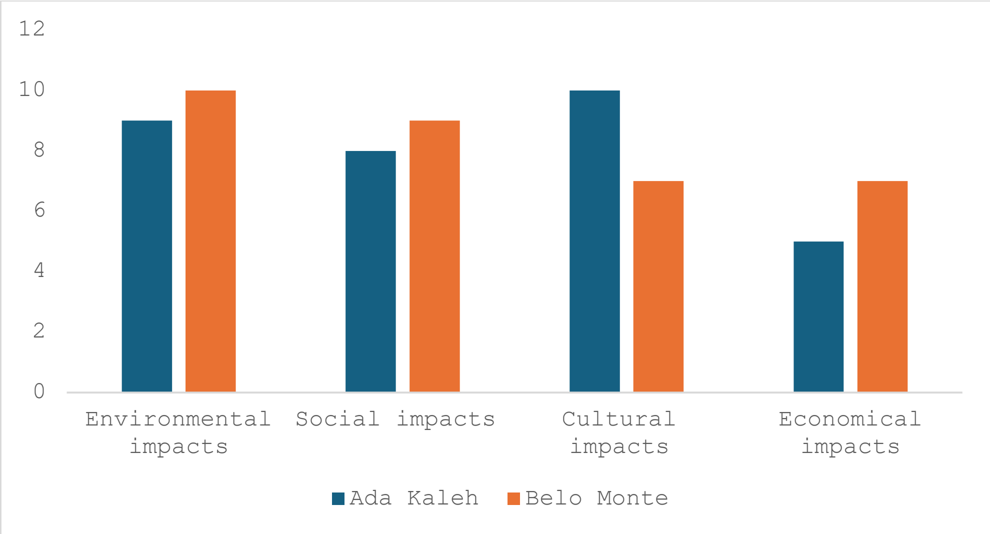

Fig. 5. *Illustration of different impacts*

The Iron Gate I hydroelectric dam was built in the 1960s and 1970s as a joint project between Romania and Yugoslavia, intended to facilitate navigation on the Danube River while at the same time producing electricity. Construction of the dam caused the complete flooding of Ada Kaleh, an island centrally located within the Danube River. The island was inhabited by a Turkish community with a distinctive religious and cultural identity dating back centuries. Submersion of the island caused permanent damage to its cultural and historical heritage, and the relocation of its inhabitants was carried out in such a way that was restricted and did not maintain the local traditions' continuity.

The Belo Monte dam, located on the Xingu River of the Brazilian state of Pará, is among the largest infrastructure projects of Latin America. The justification for its construction is parallel to that of the Ada Kaleh project, i.c., to meet national energy needs and promote local development. Nevertheless, unlike the setting of Ada Kaleh, the Belo Monte hydroelectric power plant is in the environmentally vulnerable Amazon basin, resulting in direct implications for multiple indigenous and riverside populations. It is estimated that more than 40,000 people have experienced negative impacts from this project, in addition to negative impacts on biodiversity, the hydrological cycle of the river, and increased deforestation in the region.

Both endeavors were marked with significant challenges, manifesting in an wide-scale mobilization of human and material resources. However, the political contexts and state policies under which these endeavors took place were clear. The Ada Kaleh endeavor, tied to Iron Gate I, was implemented under a communist governance well-known for its limited public participation, during a moment in time when concerns pertaining to environmental and cultural rights were yet to gain prominence. Contrarily, the Belo Monte endeavor in Brazil was implemented within a democratic system, regulated by strict environmental protection and the need for consultations among indigenous peoples; however, this requirement, although seemingly met, was criticized for the superficiality of its nature and ineffectiveness.

Another point of difference is the approaches taken in mitigation measures. In the case of Ada Kaleh, the resettlement program was incomplete and symbolic, with the relocation of some of its key elements to Simian Island; in this, however, the transfer was made without the preservation of cultural continuity and at a great loss of cultural heritage. On the other hand, in the Belo Monte case, although resettlement schemes and economic reparations were implemented, many communities were eventually left stranded, suffering from poor infrastructure and the disruption of traditional ways of life. In both cases, clearly the measures taken to compensate were inadequate in restoring previous standards of living. The Ada Kaleh Iron Gate and Belo Monte hydroelectric dams are thus examples of the degree to which megaprojects can provoke such deep environmental, social, economic, and cultural perturbations. Despite the gap of decades and physical distance between them, the two projects shared the common challenge of balancing energy production with the conservation of ecosystems and cultural identity. This comparison illustrates that, despite advancements in legislation and technology, large-scale infrastructure projects often lack the foresight needed to anticipate long-term socio-environmental consequences, exacerbated by poor planning for sustainability and little consultation with affected people.

Both the Belo Monte and Ada Kaleh projects have been linked to serious ecological consequences. Inundating the Ada Kaleh island led to the destruction of a unique riverine ecosystem, as well as an irreversible change during the Danube River. In addition, the transformation of the natural landscape into a large reservoir further interrupted the surrounding topography and biodiversity. The issues connected to the Belo Monte project are even more complex. The construction of the Belo Monte hydroelectric plant required the clearing of large portions of the Amazon rainforest, hence posing a threat to the biodiversity of one of Brazil's most environmentally vulnerable areas. Additionally, the diversion of the water from a portion of the Xingu River has reduced water flow in communities with indigenous peoples, thereby impacting their fishing, farming activities, and general water supply.

4. Conclusion

This study set out to examine the environmental and socio-cultural consequences of large-scale hydroelectric construction through a comparative analysis of the Ada Kaleh and Belo Monte projects. The analysis revealed that despite differences in geographic, political, and temporal contexts, both developments led to substantial ecological disruption, community displacement, and cultural loss. These parallels highlight ongoing difficulties in reconciling national energy agendas with environmental sustainability and social equity. The findings highlight the urgent need for more inclusive planning processes, rigorous environmental impact assessments, and culturally sensitive resettlement strategies. While the cases differ in their scale and mitigation efforts, both demonstrate the limitations of current practices in anticipating long-term consequences. Future research should explore more adaptive, participatory models of infrastructure development that integrate ecological preservation and community well-being as core objectives. Ultimately, sustainable hydroelectric projects must be designed not only to generate power but to respect the landscapes and people they impact.

To move toward more responsible infrastructure development, the following points should be considered:

- Policy Reform: Governments should establish more stringent legal frameworks that mandate transparent environmental and social impact assessments before approving hydroelectric projects.
- Community Inclusion: Future projects must incorporate the voices of indigenous and local communities not as stakeholders after the fact, but as co-decision makers throughout the project lifecycle.
- Technological Innovation: Investment in smaller-scale, less invasive hydro technologies—such as run-of-river systems—can offer cleaner energy alternatives with significantly lower ecological footprints.

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