Quantifying the Opportunity Cost of Delayed Hydropower Development: A Case Study of the Batoka Gorge Hydro-Electric Scheme (1994–2024) | ZAWAFE 2025

Abstract

Timely implementation of large-scale infrastructure projects is critical for sustainable development, particularly in energy-deficient regions. This paper assesses the opportunity cost of the delayed implementation of the 2,400 MW Batoka Gorge Hydro-Electric Scheme (BGHES), a bi-national hydropower project aimed at contributing to the energy security in Zambia and Zimbabwe. Using monthly historical flow data (1994–2024) from the Victoria Falls station (Nana Farms), the study quantifies the benefits foregone had the project been commissioned earlier.

Results indicate that approximately **420,501 GWh** of clean, renewable energy could have been generated over the past 31 years. At a local utility tariff of **$0.08/kWh**, this translates to a potential **gross revenue of $33.6 billion**, while the regional SAPP market rate of **$14.25/MWh** yields an alternative estimate of **$5.99 billion** in foregone revenue. After accounting for typical hydropower operational and maintenance (O&M) costs (around 3% of revenue) and corporate tax rates of 30%, the net financial loss remains substantial.

Beyond financial implications, the delayed development also represents a missed opportunity for large-scale employment creation. According to the AUDA-NEPAD PIDA Job Maximization Toolkit, BGHES could create **28,543 jobs** through the entire project development and implementation phases, comprising 4,262 direct, 20,176 indirect, and 4,105 induced jobs. A further **11,258 spillover jobs** were projected in sectors like transport, manufacturing, and tourism. The associated missed earnings as per-capita income and tax revenue further underscore the developmental opportunity lost.
While recognizing the necessity of comprehensive environmental and social safeguards, this paper underpins the need for timely, sustainable project implementation to maximize developmental returns. It recommends integrating opportunity cost assessments in early-stage project planning to better inform decision-makers and support proactive investment strategies.

Keywords: Batoka Gorge, Hydropower, Opportunity Cost, Project Delay, Renewable Energy, Employment Impact.

1. **Introduction**

Hydropower is vital to southern Africa’s energy portfolio, providing a renewable, reliable, and cost-effective solution to the region’s increasing electricity demands. In Zambia and Zimbabwe, where energy deficits continue to hinder economic growth and social development, initiatives such as the Batoka Gorge Hydro-Electric Scheme (BGHES) are crucial. The BGHES, a proposed 2,400 MW bi-national hydropower scheme along the Zambezi River, can significantly enhance regional energy security, reduce reliance on fossil fuels, and provide a stable foundation for industrial growth.

However, since its conceptualization in the mid-1990s, the BGHES has faced prolonged delays due to institutional, financial, and regulatory obstacles. As of 2024, the project remains unconstructed. These delays have not only postponed the delivery of clean, renewable energy to the grid but have also resulted in significant economic and development opportunity costs.

Beyond the energy dimension, large-scale infrastructure projects such as BGHES offer significant employment and socio-economic development potential. According to projections by the Zambezi River Authority using the AUDA-NEPAD PIDA Job Maximization Toolkit, the BGHES could create over 28,500 jobs during its construction phase, including direct employment in engineering and construction, indirect jobs in supply chains, and induced jobs from increased local economic activity. An additional 11,258 spillover jobs are estimated in sectors such as transport, manufacturing, and tourism. These employment opportunities are crucial given the high youth unemployment rates and the need for inclusive economic growth in both Zambia and Zimbabwe.

The compounded impact of delayed project execution includes not only the loss of power generation and revenue but also the forfeiture of critical employment and skills-building opportunities. This paper quantifies the opportunity cost of the delayed implementation of BGHES by assessing foregone energy production and associated revenues, as well as missed employment creation, using data derived from historical flows and feasibility studies.

2. Methodology

The methodology for this study is grounded in a secondary analysis of hydrological, technical, and economic data previously developed for the Batoka Gorge Hydro-Electric Scheme. The approach integrates data from three core sources: The Engineering Feasibility Study (EFS) conducted in 2019 by Studio Pietrangeli, historical hydrological flow records from Nana’s Farm (Victoria Falls station), and economic parameters aligned with the Southern African Power Pool (SAPP) market and local utility tariffs.

2.1. Hydrological Assessment:

The hydrological component of the methodology utilizes mean daily flow records from the Nana’s Farm gauging station, covering 31 years from 1994 to 2024. This dataset provides a robust basis for evaluating the volume of water that would have been available to generate power at the Batoka Gorge site. Flow values were analyzed on an annual basis to determine the frequency and extent to which natural river discharge exceeded the minimum required design flow of 1,645 m^3/s, the threshold identified by Studio Pietrangeli for full-capacity generation of 2,400 MW.

2.2. Energy Generation Estimation:

The estimated energy generation for each year is based on hydropower generation curves and Geofat triangle diagrams derived from the 2019 EFS. A static reference model was applied, using the established relationship between flow volume and turbine output efficiency. Full-capacity production was assumed whenever mean monthly flows met or exceeded the 1,645 m³/s threshold. This allowed a year-by-year estimate of potential energy output, culminating in an aggregate energy opportunity figure for the full analysis period.

Energy Estimation Formula:

For any year with average flow Q (m³/s):

$$P = \frac{Q}{1645} \times 2400$$

$$\therefore E = P \times 8760$$

Where:

P is the power output (MW)

E is the annual energy output (MWh)

8760 is the number of hours in a year

2.3. Revenue and Economic Opportunity Calculation:

An Economic assessment was carried out using two pricing scenarios:

- Local utility rate of $ 0.08/kWh (equivalent to $ 80/MWh), reflecting the typical end-user tariff.
- SAPP average market rate of $ 14.25/MWh, representing a more conservative wholesale trading rate for surplus energy exports.

  Gross Revenue Calculation:

  Gross Revenue = E × Tariff

  Where Tariff is either:
  - $0.08/kWh (local utility)
  - $14.25/MWh (SAPP average)

From these revenue estimates, the following deductions were made:

- Operational and Maintenance (O&M) costs were assumed at 3% of gross revenues, based on hydropower sector benchmarks.
- Corporate taxation was applied at 30% of taxable income (gross revenue minus O&M).

These assumptions allowed the calculation of net annual and cumulative financial opportunity costs.

2.4. Employment Impact Estimation:

To estimate the employment opportunity cost, the study references job creation data derived from the application of the AUDA-NEPAD PIDA Job Maximization Toolkit. This toolkit was used by the Zambezi River Authority in 2019 to assess the full employment potential of BGHES. The framework identifies:

- Direct jobs created during project construction (engineers, technicians, skilled and unskilled laborers).
- Indirect jobs in support industries and materials supply chains.
- Induced jobs generated through local spending effects.

- Spillover jobs in broader sectors such as transport, tourism, and services.

The total projected job creation was 28,543 during construction, plus 11,258 spillover jobs. These figures were used as proxies for the socio-economic opportunity cost of the project delay.

2.5. Limitations:

While this methodology is grounded in robust data and validated technical references, it does not incorporate real-time plant factor variability or seasonal load fluctuations. It assumes linear generation based on flow thresholds and omits transmission and distribution losses. Additionally, employment estimates are modelled projections and not actual observed figures. This conservative but comprehensive methodology ensures that the estimates presented are grounded in real engineering and economic principles, while maintaining transparency around assumptions and simplifications.

3. Results and Discussion

Based on the 2019 Engineering Feasibility Study baseline, the Batoka Gorge Hydro-Electric Scheme could have produced approximately **420501027.24 MWh** between 1994 and 2024 if it had been operational. The calculated potential revenue under the local utility tariff rate of $0.08/kWh stands at approximately **$33,640,082,179.27.** Using the SAPP market rate of $14.25/MWh**,** the potential revenue is about **$5,992,139,638.18**. After accounting for 3% O&M costs and a 30% corporate tax rate, the estimated net foregone revenue remains significant.

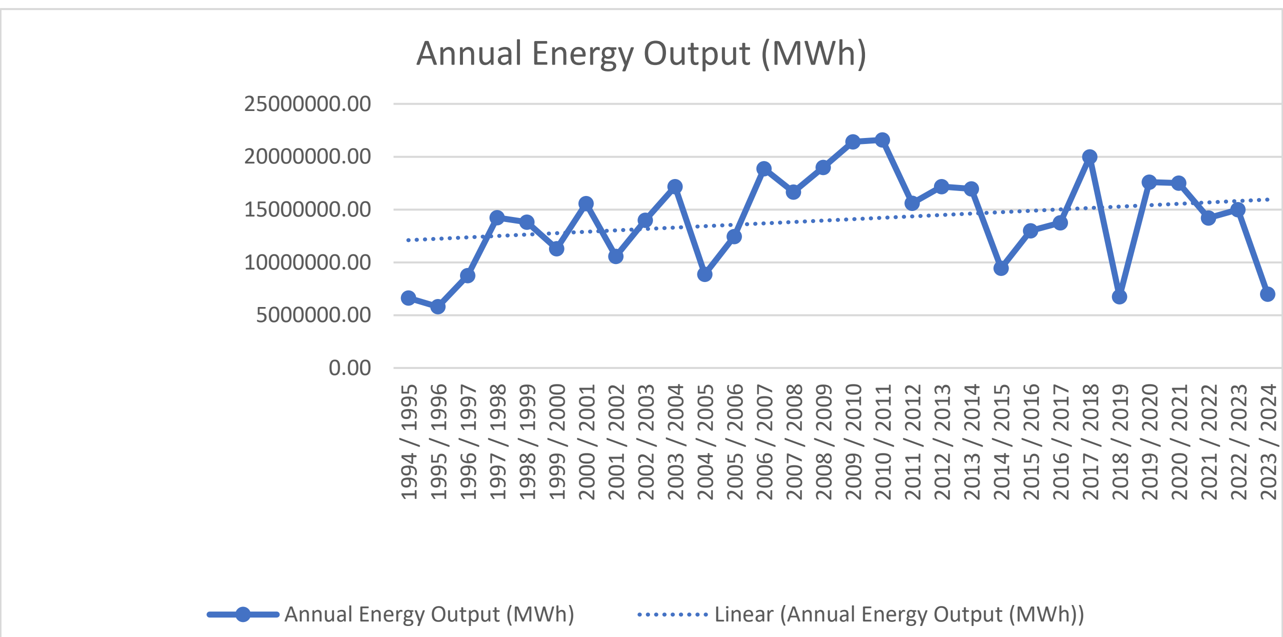

Figure 1: Annual energy generation potential (GWh) for the Batoka Gorge Hydro-Electric Scheme (1994–2023) based on historical flow data from Nana's Farm.

The long-term delay in implementing the project implies that Zambia and Zimbabwe missed not only critical revenues but also the economic multiplier effects associated with infrastructure-led growth. Electricity shortfalls continue to hinder industrial expansion, export competitiveness, and rural electrification goals in both countries. The BGHES could have played a transformative role by stabilizing the power grid, lowering electricity costs over time, and fostering private sector development.

In terms of employment, the PIDA Job Maximization Toolkit (2019) application indicated a total of 28,543 jobs would be generated during the construction phase. These comprise:

- 4,262 direct jobs (e.g., engineers, construction workers, and technical experts),
- 20,176 indirect jobs (e.g., supply chain support industries such as steel and cement), and
- 4,105 induced jobs (e.g., resulting from increased household income and consumption).

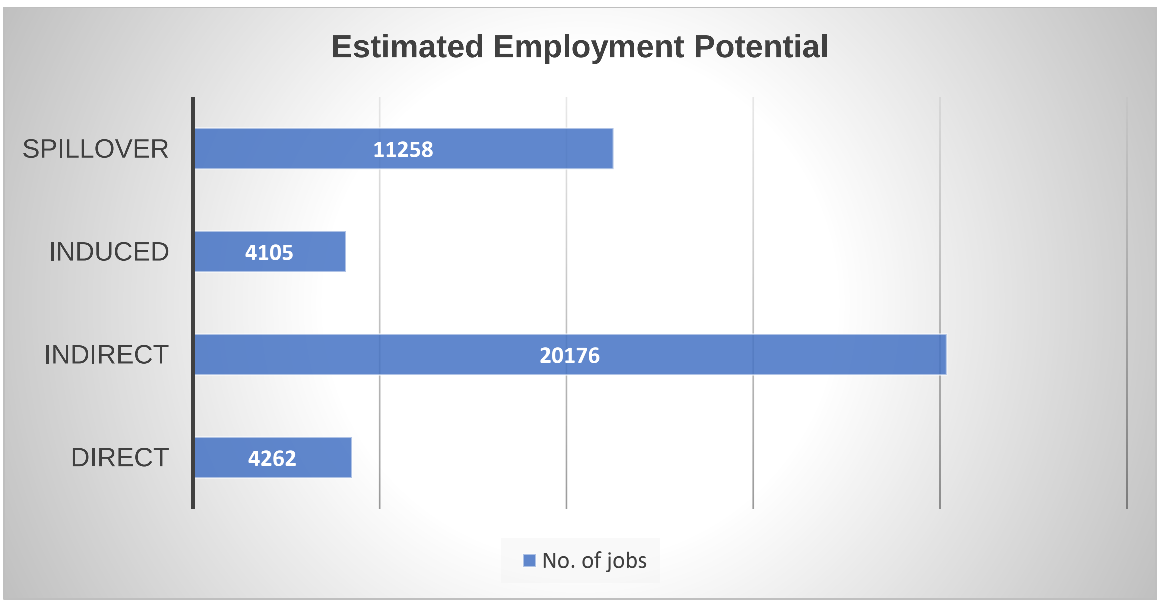

Figure 2: Estimated employment potential from the implementation of the Batoka Gorge Hydro-Electric Scheme, categorized by job type.

Additionally, 11,258 spillover jobs were projected in sectors such as tourism, transport, and manufacturing. The loss of these opportunities is significant in the context of high youth unemployment and limited job creation in rural and peri-urban areas. Delayed infrastructure not only postpones job creation but also undermines the development of local skills and expertise, especially in specialized fields such as dam construction, hydropower operations, and high-voltage engineering.

Furthermore, the employment potential is linked to capacity-building and local content development. The missed opportunities extend to technical and vocational training programs that could have been institutionalized around BGHES. The lack of timely implementation thus represents a dual loss: immediate employment and long-term workforce development.

These findings emphasize that delays in hydropower project implementation should not be viewed solely through a financial lens. The broader developmental costs missed jobs, stunted industrial growth, and reduced resilience to climate variability, paint a more comprehensive picture of the opportunity cost incurred. Accelerating the pace of decision-making, addressing regulatory and financing bottlenecks, and institutionalizing cost-of-delay analyses in project preparation frameworks are necessary steps toward better infrastructure governance.

4. **Conclusion and Recommendations**

The Batoka Gorge Hydro-Electric Scheme (BGHES) presents a compelling case of the high developmental costs associated with delays in large-scale infrastructure implementation. The foregone energy generation of over 420,000 GWh represents a substantial loss in renewable electricity that could have reduced power deficits, enhanced regional grid stability, and fueled economic growth across Zambia and Zimbabwe. Moreover, the financial implications—estimated at over $33 billion in local revenue equivalents—reflect a critical gap in resource mobilization that could have been reinvested in other priority sectors.

Equally significant are the missed employment and socio-economic benefits. With over 28,000 jobs directly, indirectly, and induced through the construction phase alone and more than 11,000 additional spillover jobs, BGHES had the potential to serve as a cornerstone for workforce development, especially for youth and underserved communities. Delayed project timelines hinder not only the creation of these jobs but also the momentum for skills development, institutional learning, and long-term sectoral capacity.

To avert similar losses in the future, this paper recommends the following:

1. Institutionalize Opportunity Cost Analysis: Integrate opportunity cost metrics into project preparation and approval frameworks to enable evidence-based decision-making.
2. Strengthen Inter-Governmental Coordination: Enhance collaboration between national, regional, and bi-national agencies to streamline project development and minimise bureaucratic inertia.
3. Accelerate Financial Closure Mechanisms: Adopt innovative financing strategies, including blended finance, green bonds, and infrastructure investment platforms, to reduce delays related to funding.
4. Mainstream Local Content and Job Maximization: Embed employment planning tools like the PIDA Toolkit into project execution strategies to ensure timely delivery of job and skills outcomes.
5. Enhance Stakeholder Engagement: Foster inclusive dialogue and community participation to promote social license and long-term project sustainability.

In summary, the delay in implementing BGHES ought to serve as a vital lesson regarding the costs of inaction. Hydropower remains a crucial enabler of Africa's transition to sustainable and inclusive growth. Ensuring timely implementation is not just an operational concern but a developmental necessity.

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Appendices

Annex 1: **Hydropower Generation Assumptions**

Source: *Studio Pietrangeli, 2019 Engineering Feasibility Study (EFS)*

Flow Rate (m^3/s)	Estimated Output (MW)
≥1645	2400MW
< 1,645	Proportional Derating Based on Flow

Note: These estimates are derived from the Geofat triangle diagrams provided in the 2019 EFS, which link flow rates to hydropower output under design conditions.

Annex 2: **Estimated Annual Energy and Revenue Summary**

Estimated Energy Generation and Associated Revenue Losses from Delayed Implementation of BGHES (1994–2024)"					
Year	**Annual Mean Flow (m3/s)**	**Power Output (MW)**	**Annual Energy Output (MWh)**	**Gross Revenue (USD) Local Rates**	**Gross Revenue (USD) SAPP**
1994 / 1995	518.33	756.23	6624572.70	$ 529,965,816.00	$ 94,400,160.97
1995 / 1996	453.36	661.43	5794167.18	$ 463,533,374.50	$ 82,566,882.33
1996 / 1997	684.91	999.27	8753583.27	$ 700,286,661.28	$ 124,738,561.54
1997 / 1998	1113.01	1623.84	14224868.73	$ 1,137,989,498.15	$ 202,704,379.36
1998 / 1999	1079.26	1574.60	13793527.76	$ 1,103,482,220.67	$ 196,557,770.56
1999 / 2000	883.36	1288.80	11289844.21	$ 903,187,536.76	$ 160,880,279.99
2000 / 2001	1218.01	1777.03	15566796.41	$ 1,245,343,712.93	$ 221,826,848.87
2001 / 2002	825.74	1204.72	10553376.99	$ 844,270,158.91	$ 150,385,622.06
2002 / 2003	1094.29	1596.53	13985630.38	$ 1,118,850,430.30	$ 199,295,232.90
2003 / 2004	1343.84	1960.62	17175017.25	$ 1,374,001,379.69	$ 244,743,995.76
2004 / 2005	694.99	1013.97	8882344.86	$ 710,587,588.68	$ 126,573,414.23
2005 / 2006	974.32	1421.50	12452381.13	$ 996,190,490.09	$ 177,446,431.05

2006 / 2007	1476.20	2153.72	18866610.15	$ 1,509,328,812.32	$ 268,849,194.69
2007 / 2008	1303.16	1901.27	16655117.57	$ 1,332,409,405.68	$ 237,335,425.39
2008 / 2009	1485.85	2167.81	18989978.40	$ 1,519,198,271.85	$ 270,607,192.17
2009 / 2010	1675.32	2444.24	21411508.54	$ 1,712,920,682.89	$ 305,113,996.64
2010 / 2011	1689.34	2464.69	21590719.22	$ 1,727,257,537.21	$ 307,667,748.82
2011 / 2012	1220.63	1780.86	15600358.97	$ 1,248,028,717.81	$ 222,305,115.36
2012 / 2013	1342.75	1959.03	17161085.89	$ 1,372,886,871.51	$ 244,545,473.99
2013 / 2014	1325.64	1934.06	16942347.07	$ 1,355,387,765.55	$ 241,428,445.74
2014 / 2015	739.56	1079.00	9451996.23	$ 756,159,698.12	$ 134,690,946.23
2015 / 2016	1015.61	1481.74	12980048.68	$ 1,038,403,894.57	$ 184,965,693.72
2016 / 2017	1075.58	1569.23	13746442.09	$ 1,099,715,366.89	$ 195,886,799.73
2017 / 2018	1564.67	2282.80	19997294.22	$ 1,599,783,537.22	$ 284,961,442.57
2018 / 2019	527.27	769.27	6738762.74	$ 539,101,018.97	$ 96,027,369.00
2019 / 2020	1375.64	2007.01	17581397.17	$ 1,406,511,773.87	$ 250,534,909.72
2020 / 2021	1368.73	1996.94	17493172.39	$ 1,399,453,791.46	$ 249,277,706.60
2021 / 2022	1111.89	1622.21	14210597.78	$ 1,136,847,822.30	$ 202,501,018.35
2022 / 2023	1173.22	1711.68	14994335.07	$ 1,199,546,805.55	$ 213,669,274.74
2023 / 2024	547.17	798.30	6993144.22	$ 559,451,537.54	$ 99,652,305.12
	32901.65	**48002.40**	**420501027.24**	**$ 33,640,082,179.27**	**$ 5,992,139,638.18**

Note:

- Annual mean flows were used to assess the operational performance potential of the BGHES across a 30-year historical period.
- Calculations assume 8,760 hours/year of operation and linear scaling of output below 1,645 m³/s. Net revenues factor in 3% O&M and 30% corporate tax.

Annex 3: **Employment Estimation Breakdown**

Source: AUDA-NEPAD PIDA Job Maximization Toolkit (Applied to BGHES by ZRA, 2019)

Job Category	Estimated Jobs	Description
Direct	4,262	Core project roles including engineers, site managers and technicians.
Indirect	20,176	Supply chain roles in sectors such as cement, steel, and transport.
Induced	4,105	Jobs resulting from local consumption by workers (retail, services, etc.)
Spillover	11,258	Additional employment in the broader economy (tourism, logistics, etc.)
Total	**39,801**	

Notes:

- Estimates based on "job-years," i.e. one job sustained for one year.
- PIDA Toolkit applies economic multipliers to total investment and project lifecycle phases.
- Spillover effect estimation includes forward linkages in the transport, hospitality, and services sectors.

Annex 4: **Glossary of Technical Terms and Acronyms**

Term / Acronym	Definition
BGHES	Batoka Gorge Hydro-Electric Scheme
GWh	Gigawatt-hour – A unit of energy equivalent to one billion watt-hours
MW	Megawatt – A unit of power equal to one million watts
m^3/s	Cubic meters per second – A unit of flow rate used in hydrology
O&M	Operation and Maintenance – Recurring costs required to operate infrastructure
SAPP	Southern African Power Pool – Regional electricity market covering Southern Africa
PIDA	Programme for Infrastructure Development in Africa – An initiative by the African Union
PIDA Toolkit	A job estimation and workforce planning tool developed by AUDA-NEPAD for large infrastructure
Geofat Triangle	A graphical method used to depict plant capacity versus available flow regimes in hydropower
Job-Year	A unit representing one full-time job for one year
