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From Delay to Delivery: Tackling Time and Cost Risks in Hydropower Projects

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Abstract: This study examines the persistent global problem of time and cost overruns in hydropower projects, with emphasis on India. Although hydropower is central to renewable energy strategies and grid stability, project implementation is often hindered by major delays and budget escalations. Since 2000, international data indicate average cost overruns above 30% and schedule delays over 18% (Ansar et al., 2014). The research identifies the root causes of these overruns, evaluates their prevalence in India, reviews case studies, compares national and global trends, and analyses factors such as regulatory complexity, geological challenges, technological integration, and managerial practices. It also highlights best practices to improve project outcomes.

Both technical and non-technical factors drive overruns. Technical contributors include complex engineering demands, construction inefficiencies, procurement delays, contractor underperformance, and frequent rework (Debnath, 2025). Non-technical drivers include environmental and social issues, lengthy approval processes, community opposition, political instability, natural disasters, funding constraints, and global disruptions (Debnath, 2025). Cost escalations stem from direct factors—rising material prices, design changes, unforeseen site conditions, and inaccurate estimates—and indirect ones such as inflation, interest burdens, exchange rate volatility, increased overheads, and contractual disputes (Flyvbjerg, 2006). Case studies from India and abroad show varied causes, including difficult geology, social resistance, land acquisition challenges, financial gaps, and weaknesses in planning and design (World Bank, 2020). These overruns affect not only project viability but also economic development, environmental sustainability, and societal welfare. Addressing them requires comprehensive mitigation across all project stages: rigorous planning, strong risk management, effective contract administration, strict construction oversight, and early stakeholder engagement. Adoption of technologies like BIM and digital project management tools can further enhance efficiency (International Hydropower Association, 2021). Sustainable and resilient hydropower development depends on improved governance, technology uptake, and supportive policy frameworks (Central Electricity Authority, 2022).

Key words: Hydropower projects, Time overruns, Cost overruns, Project management, Risk mitigation, Stakeholder engagement

I. INTRODUCTION

The nucleus of renewable energy programs for many countries is hydropower, which gives a significant contribution today while facilitating the development of renewable and sustainable energy systems on a grand scale (International Hydropower Association, 2021). Supplying clean electricity services for growing energy demand and enhancing grid stabilization while combating climate change, hydropower is an indispensable link towards meeting the entire globe's energy demand (World Bank, 2020). While clear, these benefits seem not to help the hydropower projects as they remain an industry of perpetual delays and cost overruns, thus diminishing their economic appeal and postponing much-anticipated benefits (Debnath, 2025). Research identifies these adversities as inherent in regional and project-specific considerations, thereby painting a picture of an industry-wide problem rather than a plethora of isolated occurrences (Debnath, 2025). An international database on hydropower showed, from the year 2000, an average of over 30% in cost overruns and generally a delay in project implementation by more than 18% (Ansar et al., 2014). Compared with earlier projects, the scheduling for these newer projects was much improved, while cost overruns continue to remain an issue in hydropower project management (Ansar et al., 2014). Frequent overruns emphasize the necessity of understanding their root causes so that future planning and implementation will be able to deliver reliable and sustainable energy through hydropower.

This work aims to provide a comprehensive and insightful analysis of the reasons behind these time and cost overruns in hydropower projects, both in India and on a global scale. The objectives of this study are multifaceted: to identify and analyse the primary factors contributing to these overruns worldwide; to examine the performance of the Indian power sector, with a specific focus on hydropower projects and the challenges they face concerning overruns; to investigate specific case studies of hydropower projects in India that have encountered substantial time and cost escalations; to compare the performance and challenges of hydropower project development across various regions and countries globally; to explore the influence of factors such as

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environmental regulations, land acquisition processes, geological uncertainties, and contractual matters in contributing to these overruns in the Indian context; to analyse the impact of technological advancements and project management methodologies on the efficiency and cost-effectiveness of hydropower projects; to present data on time and cost overruns in both tabular and graphical formats for India and the global scenario; and finally, to suggest potential best practices in project management that have led to successful outcomes in hydropower projects.

II. LITERATURE REVIEW

A systematic literature review on the works of various scholars across the globe analysing risks and overruns in infrastructure projects including hydropower schemes clearly indicates that time and cost overrun has been a recurring issue and reasons for such overruns are diverse in nature and have arisen because of inappropriate mitigation of risks associated with hydro power development (Flyvbjerg, 2006).

Scholars have endeavoured to review and analyse this phenomenon and constructed specific theory relating to the success or failure of projects. “Iron triangle” is one of the examples in the case of project management success indicators; it suggests that projects are successful when an equilibrium is maintained between time, cost and scope[1]. According to this model, changing any one of the three factors would affect the other two, which frequently leads to overruns (PureLogics, 2023). Often, it is said the essence of this framework is the clear definition at the start and continuous scope control through the life of the project.

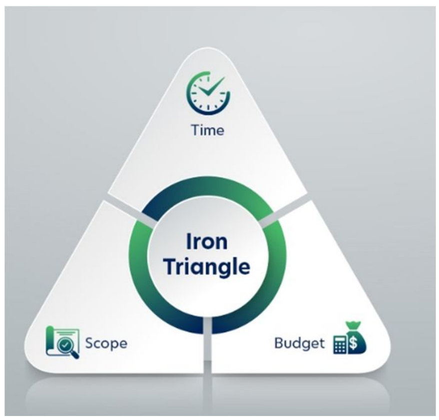

Figure 1: Iron Triangle in Project Management

Another and probably more well-known view is reference class forecasting[2]. This approach utilizes the history of similar past projects to derive more accurate estimations of cost and associated risks for the new undertakings (Flyvbjerg, 2006). This method offers a solution for containing the recognized problem of estimating costs for infrastructure projects because it allows for poor initial estimates to be improved by measurement against a larger set of completed projects (F9Finance, 2023).

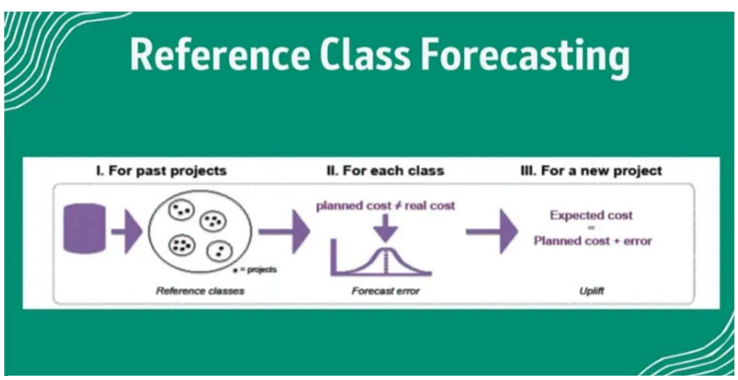

Figure 2: Reference Class Forecasting

[1] Source: https://purelogics.com/what-is-the-iron-triangle-in-project-management/
[2] Source: https://www.f9finance.com/reference-class-forecasting/

Furthermore, principal-agent theory[3] provides a distinct, but equally important view in explaining project overrun issues concerning the interest disputes and the information asymmetry that exists between project owners and contractors. This theory, which stems from transaction cost economics, centres on the argument that to align interests and reduce the risk of opportunistic behaviours, agreements must be well-structured and inflating project delays and costs controlled (Jensen & Meckling, 1976).

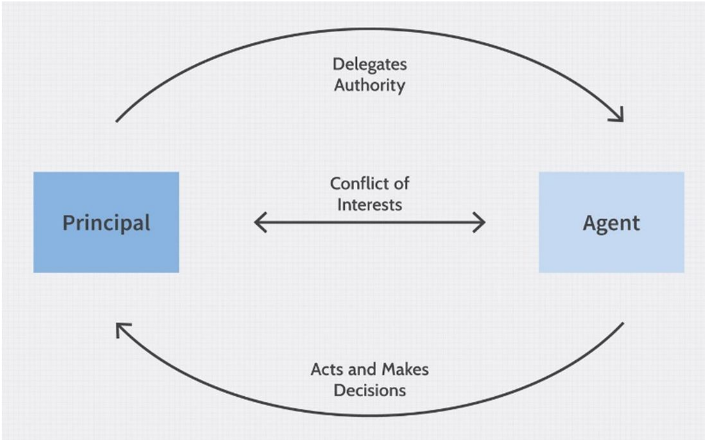

Figure 3: Schematic representation of Principal Agent Theory

An assessment of all individual studies shows that there is a universal set of factors which causes time and cost overruns on both general infrastructure and hydropower projects. They include geological uncertainties, delay in securing necessary environmental and governmental approvals, land acquisition and resettlement of project-displaced people complexities, design changes and engineering design complexities, finance and funding constraints, and contractor performance (Ansar et al., 2014). The prevalence of these causes across multiple studies and locales suggests that they are representative of endemic risk within hydropower infrastructure development. While prior research offers a firm understanding of these common causes, this study aims to further investigate the specifics and regional variations in expression of these problems within the hydropower sector, towards a more contextual and detailed examination of the problem (Debnath, 2025).

A. Hydropower Project Specific Challenges

Hydropower schemes contain inherent complexities which render them particularly vulnerable to time and cost overruns. The most significant of these is the geological uncertainties relating to dam construction and tunnel work (Ansar et al., 2014). Geological conditions in the ground are difficult to forecast precisely even with elaborate pre-construction surveys, and the revelation of new geological formations at the excavation phases can require massive redesigning, application of specialized construction techniques, and critical delays, all of which amount to higher costs. Most prospective hydropower schemes are located in remote regions characterized by poor connectivity and challenging topography, including steep and irregular terrain (Debnath, 2025). The lack of essential infrastructure makes it difficult to transport and mobilize heavy machinery, construction materials, and labour. As a result, project implementation often requires constructing access roads, bridges, and other supporting facilities, which increases capital costs and frequently extends project timelines. Adverse climatic conditions, such as intense precipitation, cloudbursts, and unexpected flooding, further complicate hydropower development by exacerbating logistical challenges (International Hydropower Association, 2021). These events often cause prolonged construction delays and work stoppages, leading to substantial cost increases. In the Indian context, project timelines are also heavily affected by delays in securing environmental and regulatory clearances. The approval process is lengthy and complex, requiring coordination with multiple government agencies, detailed environmental impact assessments, and compliance with stringent regulatory norms (Central Electricity Authority, 2022). Moreover, hydropower projects, particularly storage-based ones, frequently require the relocation of large local populations, which can trigger social unrest, legal disputes, and high rehabilitation and resettlement costs (World Bank, 2020). Inadequate attention to these environmental and social issues often results in severe project delays and may damage stakeholder reputations.

[3] Source: https://www.google.com/search?q=principal-agent+theory+image&rlz=1C1CHBD_enIN1051IN1051&oq=principal-agent+theory+image&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQIRigAdIBCTQzNThqMGoxNagCCLACAfEFFKAv6VIbbi0&sourceid=chrome&ie=UTF-8#vhid=KmBwbRs4_C-8GM&vssid=_iMUqaIiyIe6R4-EPps2QkAc_38

Finally, hydropower projects, encompassing initial planning, feasibility studies, detailed design, construction, and eventual commissioning are characterized by long gestation periods (Debnath, 2025). These long-time spans expose the projects to a greater test of potential risks and uncertainties.

These are macroeconomic adjustments, changes in government policy and regulation, technological adjustments, and unforeseen external events, and these will tend to impact longer-duration projects with a greater general probability of time and cost overruns (Flyvbjerg, 2006).

B. Causes of Hydropower Project Time Overruns

The literature review indicates that there are many interrelated causes falling into two broad categories, technical and non-technical, which account for hydropower project time overruns.

1) Technical Aspects

Engineering and design complexity is a major source of schedule delays, particularly when design changes occur later in the project lifecycle (Debnath, 2025). The intricate requirements of power generation systems, turbine foundations, and dam construction often necessitate advanced designs that must be revised as new data emerge. Such revisions typically delay schedules and require additional engineering work, material substitutions, and modifications to construction methods.

Construction-related issues also contribute significantly to cost overruns. Claims related to “poor rock,” “bad ground,” or “bad earthwork” frequently arise when unforeseen subsurface conditions are encountered during tunnelling and excavation (Flyvbjerg, 2006). These conditions may halt work, necessitate redesigns, and require specialized equipment or techniques, all of which extend project duration. Remote project locations further compound delays due to difficult equipment and material mobilization and harsh working environments (Debnath, 2025).

Delays in procuring critical equipment can also have cascading effects on project timelines (World Bank, 2020). Hydropower schemes rely on specialized components, such as turbines and generators, with long manufacturing lead times, making them vulnerable to supply chain disruptions, especially when imports are involved.

Contractor performance is another key determinant of project schedules (Ansar et al., 2014). Poor planning, ineffective resource utilization, substandard work quality, weak supervision, and delays by subcontractors can significantly hinder progress (Debnath, 2025). Additionally, rework arising from design errors or construction defects can lead to substantial time overruns, as it requires demolition, redesign, and reconstruction to rectify the issues (Debnath, 2025).

2) Non-Technical Factors

Environmental and social factors are an extremely crucial type of non-technical cause of overruns in time for hydropower projects (World Bank, 2020). Taking environmental and forest clearance from the concerned authorities may take a lengthy and complex period with sophisticated studies, public hearings, and addressing concerns raised by various stakeholders concerned. The delay during this time could hold up the whole project. Similarly, resettlement and rehabilitation of project-affected persons, land acquisition, and compensation problems can be opposed by local groups and take years of negotiation, leading to huge delays (Central Electricity Authority, 2022).

Delay in getting various government clearances and approvals other than environmental clearances, such as investment clearances and power evacuation clearances, can further hamper the progress of the project (Debnath, 2025). Delay in getting these mandatory approvals may be due to bureaucratic delays, inter-departmental coordination, and changing government priorities.

Resistance to hydropower projects by the community and social groups, usually due to environmental issues, displacement, and loss of livelihood, can result in stoppages, litigation, and protests, which can result in significant delays (International Hydropower Association, 2021). Continual government turnover is directly impacting project schedule, including the addition or deletion of funding streams, shifting regulatory regimes and priorities from administration to administration (Ansar et al., 2014). Rare but severe natural disasters like earthquakes, floods, and landslides can cause broad, deep, and immediate disruptions, by damaging finished projects, devastating established and managed transportation systems, and stopping progress on in-progress assets (World Bank, 2020). Inadequate timely financial assistance, particularly inadequate access to and inadequate projected funding, can cause holdups and drastically slow down promised work delivery (Debnath, 2025). Lastly, worldwide disruptions such as pandemics can lead to delays because of labour shortages, supply chain delays, and restriction on travel (International Hydropower Association, 2021).

C. Causes of Cost Overruns in Hydropower Projects

Hydropower project cost overruns are caused by an interdependent mix of direct and indirect factors.

1) Direct Costs

Rising prices of raw materials, such as cement, steel, and aggregates, as well as specialized equipment like turbines and generators, directly contribute to project cost escalation (Ansar et al., 2014). Volatility in international commodity markets and local supply–demand conditions further amplify these increases. Design modifications during construction and changes in project scope are also major drivers of cost overruns (Debnath, 2025). While some revisions are necessary to enhance performance or address unforeseen site conditions, frequent changes and uncontrolled scope creep significantly increase work quantities, material usage, and overall project expenses. Unanticipated site conditions, especially geological surprises during tunnelling and excavation, commonly lead to substantial cost escalation (World Bank, 2020). Encountering unexpected rock strata, water ingress, or unstable ground often requires more advanced construction techniques, additional materials, and extended labour hours. Unrealistic initial budgets and inaccurate cost estimates are also prevalent causes of overruns (Flyvbjerg, 2006). Underestimation may result from optimism bias, strategic misrepresentation during bidding, or inadequate data during feasibility assessments.

2) Indirect Costs

Time overruns are one of the leading reasons for indirect cost overrun in hydropower projects (Ansar et al., 2014). Delays in the project result in the extension of periods over which interest has to be paid on construction loan, leading to a massive increase in total interest paid throughout the project finance period. This is particularly so in the later years of construction when significant capital has already been incurred (World Bank, 2020). Both exchange rate movements and inflation can potentially influence the indirect costs significantly, especially in long projects and foreign-dependent materials or foreign funding (Flyvbjerg, 2006). Unforeseen increases in inflation rates will tend to erode the purchasing power of the project budget, while unfavourable exchange rate movements can increase the cost of imported components and services. Overruns in time lead to higher establishment cost of the project (Debnath, 2025). Maintaining project management personnel, site offices, and other infrastructures active for longer than intended initially raises the overall project overheads. Claims under contract due to delays, scope changes, or unforeseen events can cause large indirect costs in the form of legal fees, arbitration fees, and potential settlement payments (Ansar et al., 2014). Lack of skilled manpower, poor productivity of employed labours also play a deterrent role to project progress with consequential effect of time and cost overrun. Finally, a lack of funds for either the prime contractor or developer can lead to delayed payments, work stoppages, and, ultimately, higher costs for the project (World Bank, 2020).

D. Case Studies of Time and Cost Overruns in Hydropower Projects

Delayed hydropower projects are a significant global issue, leading to substantial cost overruns, deferred revenue, and various socio-economic and environmental consequences. These delays are a result of complex combinations of various causal factors related to technical, environmental, social, political, and financial factors (Ansar et al., 2014). Some case studies of delayed hydropower projects from around the world are cited below, briefly highlighting the reasons behind the delays and their impacts for brevity of understanding on the reasons and causal factors for overruns:

1) Punatsangchhu I and II Hydroelectric Projects

The Punatsangchhu I (1200 MW) and Punatsangchhu II (1020 MW) hydropower projects in Bhutan have faced significant delays primarily due to adverse geological conditions, including slope instability and frequent geological surprises during underground excavation. These challenges have led to major cost escalations, with Punatsangchhu I rising from an initial estimate of BTN 35.15 billion (USD 425 million) to BTN 93.76 billion (USD 1.13 billion) while still remaining incomplete. Punatsangchhu II has experienced similar prolonged delays and substantial budget overruns.

2) West Seti Hydropower Project

The 750 MW project in Nepal, initiated in 1994, has faced extensive delays due to a combination of public resistance over electricity-sharing arrangements and concerns about social and environmental impacts. Progress was further impeded by land acquisition challenges, resettlement and rehabilitation difficulties, and the initial developer's inability to finalize a power purchase agreement with India. The situation worsened when the Asian Development Bank (ADB) withdrew financial support in 2010. As a result, Nepal has been unable to tap into a major energy resource, exacerbating the country's energy deficit and creating prolonged uncertainty and hardship for communities in the project area

3) Neelum – Jhelum Hydropower Plant

The 969 MW project on Pakistan's Neelum River experienced significant delays, initially due to funding shortages and later due to design changes and allegations of fraudulent practices in equipment procurement. These issues led to substantial cost overruns and postponed project commissioning, prolonging Pakistan's dependence on alternative energy sources and adversely affecting both its energy security and economic development.

4) Bujagali Hydropower Project

The hydropower project on Uganda's Nile River faced an 18-year delay from inception to completion, primarily due to a range of environmental, social, and economic challenges. As a result, project costs rose sharply from USD 580 million to USD 902 million, with some independent assessments suggesting even higher figures. The prolonged timeline also postponed the project's anticipated benefits, including increased electricity generation, poverty alleviation, and carbon mitigation.

5) Kariba Dam Hydro Electric Project

The 2,010 MW Kariba hydropower system, located on the Zambezi River between Zambia and Zimbabwe, comprises the Kariba South Bank Power Station in Zimbabwe (1,050 MW after a 300 MW expansion completed in 2018) and the Kariba North Bank Power Station in Zambia (960 MW, expanded by 360 MW in 2013). In recent years, historic declines in rainfall have caused severe water shortages, forcing Zimbabwe to halt generation at the South Power Station. This underperformance underscores the growing vulnerability of hydropower infrastructure to climate-related variability.

6) The Sondu-Miriu Hydroelectric Project

The 60 MW Sondu-Miriu Hydropower Project in Kisumu County, Western Kenya, experienced significant delays, with its planned 2005 completion pushed to November 2011—an extension of about six years. The overruns were driven by delayed contractor payments, slow resource mobilization, design and site management issues, funding disbursement delays, work stoppages, and inadequate planning and risk management. As a result, the project's cost rose from an estimated KES 18 billion (JPY 8,156 million) to JPY 9,088 million—about 111% of the original budget—with an additional KES 2 billion required to complete the second phase following a four-year construction hiatus.

7) The Diamer-Basha Dam project

The 4,500 MW project on the Indus River, located between Khyber Pakhtunkhwa and Gilgit-Baltistan and roughly 315 km upstream of the Tarbela Dam, has experienced substantial delays, with its completion date pushed from February 2029 to an estimated December 2030 and liabilities extending to 2032. Key contributors to the 22-month delay include security challenges, repeated revisions to the river diversion scheme, relocation of the Karakoram Highway, delayed payments, inadequate financing plans, and bureaucratic and political obstacles. These issues have driven a dramatic cost escalation: from the initially approved 2018 estimate of Rs. 479 billion to between Rs. 1,049 billion and Rs. 1,400 billion as reported in 2024–2025, an increase of over 119%. When power generation infrastructure is included, some estimates place the total cost near Rs. 2,400 billion.

8) Ituango plant

Colombia's 2,400 MW run-of-river project, the nation's largest, has faced persistent delays since construction began in 2010, most notably after the collapse of an auxiliary diversion tunnel in April 2018. This incident underscores the susceptibility of major hydropower projects to unforeseen technical failures during construction. The resulting disruptions triggered substantial cost overruns, with reports indicating an additional US$1.5–2.5 billion in expenses due to the emergency and subsequent delays, pushing total project costs far beyond initial estimates.

9) Some more references from South America

Several hydropower projects in Bolivia under China's Belt and Road Initiative have experienced delays primarily due to local opposition concerning negative environmental and social impacts, as well as broader political instability. While some projects like San Jose I and II have been completed, larger ventures such as Ivirizu and Rositas have faced significant delays or have not commenced construction. The Ecuadorian Coca Codo Sinclair project, which is the biggest hydropower plant in Ecuador, was completed but with considerable problems, such as corruption scandals and structural defects. Such issues, in addition to negative environmental and local community effects, led to delays and cost increases during its construction.

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10) Some cases from India

A number of hydropower projects in Himachal Pradesh, India, have shown large cost overruns, and project size and the duration of the implementation phase have been found to be major contributing factors. Greater projects and projects with longer construction times are naturally more complicated and prone to unforeseen circumstances and thus costlier.

- Myntdu Leshka Hydroelectric project: The 84 MW Myntdu Leshka Hydroelectric Project on the Myntdu River in Meghalaya experienced substantial delays beyond its original five-year completion target set in 1999, with the first unit commissioned only in December 2011 and the remaining units coming online between 2011 and 2013. The time overruns stemmed from multiple factors, including delays in obtaining clearances, geological surprises, funding and financial management challenges, contractual issues, and adverse weather conditions marked by heavy precipitation. The project has also become a key case study for assessing time and cost overruns under uncertainty; although initially estimated at ₹3,630 million, a fuzzy-based expert system projected cost escalations reaching approximately ₹1,286.83 crore.
- Subansiri Lower Hydroelectric Project: The 2,000 MW Subansiri Lower Hydroelectric Project in Arunachal Pradesh, executed by NHPC Ltd., has faced prolonged delays since receiving techno-economic clearance in 2003. Initially expected to be commissioned between 2010 and 2012, the project was stalled for years due to widespread protests over environmental and safety concerns in a seismically active zone, as well as regulatory hurdles. Construction was suspended in December 2011 and resumed only in October 2019 after key clearances, including from the National Green Tribunal. Now projected for completion in May 2026, the project has incurred a time overrun of 13–15 years. These delays have driven extreme cost escalation: the original estimate of ₹6,285 crore (2002 price level) rose to about ₹10,780 crore by 2013, ₹19,496 crore by 2019, and nearly ₹19,992 crore in 2020, with late-2024 reports placing the cost around ₹26,000 crore, amounting to a more than 314% increase, making it one of India's most expensive hydropower overruns.
- Maheshwar Hydropower Project: The 400 MW Maheshwar Hydropower Project on the Narmada River in Madhya Pradesh, awarded to a private developer in 1993, experienced severe and prolonged delays, particularly in resettlement and rehabilitation (R&R) processes originally targeted for completion by 1997–98. Construction was repeatedly interrupted, leading to an estimated time overrun of about 17 years, the highest among delayed hydropower projects in India as of 2017. Despite substantial physical progress, the plant never became fully operational, and the state government ultimately cancelled all project contracts in September 2022. Key drivers of delay included R&R challenges, financial difficulties, allegations of irregularities, disputes over the power purchase agreement, environmental clearance issues, and the withdrawal of international partners. The project's cost rose from an initial estimate of ₹1,569 crore to between ₹4,700 crore and ₹6,000 crore by 2015, reflecting a cost overrun of over 200%. Broader financial concerns were also raised, with some projections suggesting liabilities as high as ₹1,400 billion or up to ₹42,000 crore in PPA-driven payments over 35 years, underscoring the project's long-term economic burden. The Maheshwar case illustrates the inherent risks and complexities of privately driven hydropower initiatives in India, especially regarding land acquisition, social and environmental safeguards, financial viability, and the critical need for robust government oversight.
- Parbati II Hydropower Project: The 800 MW Parbati II Hydroelectric Project in Himachal Pradesh's Kullu district has suffered extensive delays, far exceeding its original completion targets of 2009–2013 following techno-economic clearance. Under construction for more than two decades, the project has only recently begun commissioning some units in March–April 2025. By early 2025, it had recorded a time overrun of approximately 187 months, more than 15 years. The delays stem from severe geological challenges in tunnelling, natural events, contractual disputes, and regulatory bottlenecks. These issues have driven substantial cost escalation: from an approved estimate of ₹3,919.59 crore (2001 price level) to ₹9,394.80 crore by 2018 and over ₹11,134 crore by 2023. Early 2025 data place the anticipated cost at around ₹13,045 crore, reflecting a cost overrun of about 233%, more than triple the original estimate

E. Consequences of Time and Cost Overruns on Hydropower Projects

In addition to costly delay and exponential impacts on developers and investors, time and cost overruns in hydropower projects have significant downstream ramifications. Overruns can affect not only the project's eventual financial viability but the economy overall, the social equity of communities impacted by the project, and the natural environment.

1) Financial Impacts

The direct consequence of cost overruns is the drastic increase in the total cost of the project, often leading to budget deficits. Such extra costs can be transferred as increased electricity prices to consumers, thus undermining premium power's affordability. Cost overruns can also drastically reduce the profitability and return on investment of project developers, rendering investment in the industry less feasible in the future. In extreme scenarios, excessive cost inflation can endanger project financing to the point of abandonment, especially when additional funding cannot be mobilized.

2) Economic Effects

Delays to projects cause a lag in the expected economic returns, which will hinder overall development, particularly in regions where access to stable power is crucial to economic development Delays also influence national energy security by delaying the addition of planned generation capacity, and consequently, will increase the reliance on less sustainable forms of energy. Time delays for the developer and the nation mean a loss of potential revenue generation due to the delayed sale of electricity.

3) Social Impacts

Cost and time overruns can have significant social implications, chief among them for the impacted communities. The communities may endure anguish and hardship brought about by prolonged uncertainty about resettlement, compensation, and the future of the project. The necessity of land acquisition for development of hydro power often leads to resistance from landowners (PWC 2014). Agencies responsible for implementing these megaprojects face significant challenges in addressing the concerns of landowners within the scope of the project's execution (Mcwilliams et al. n.d.; Mevada and Devkar 2017; PwC 2017). The problems arisen in timely land procurement are leading to stoppages and suspension in the construction activities. To name a few projects in India, Thein Dam (Rajasthan), Doyang HEP (Nagaland), Ghatgar pumped storage plants (Maharashtra) are the projects impacted due to land acquisition problems (Ramanathan K and P. Abeygunawardena 2007). Repeated delays would erode public confidence in the project developers themselves, as well as in the relevant government agencies, and would have a bias towards social unrest. This has resulted in delay in accrual benefits.

4) Environmental Impacts

Environmental Issues: Indian Hydropower projects often faced resistance due to environmental concerns such as displacement, submergence, deforestation, wildlife protection, and the impact on river ecosystems (Vn and Sudhakumar n.d.). Several hydropower projects have faced challenges related to environmental issues. Even if the necessary approvals are granted, activists still have the option to seek judicial recourse by filing a petition with the National Green Tribunal (NGT), which often results in expensive delays. Some notable examples include Tehri Hydroelectric Project (Uttarakhand) (Verma et al. 2022), Narmada Valley Project (Madhya Pradesh and Gujarat) (Ranjit Dwibedi 1997), Kishanganga Hydroelectric Project (Jammu & Kashmir, India)[4], Teesta Stage-IV (Sikkim, India)[5].

These cases highlight the critical need to address environmental and social concerns early in the project planning phase to avoid delays and financial setbacks.

F. Gap in Knowledge

Based on the review of current literature on risk management and cost/time overruns in hydropower projects, a number of gap areas have been identified that require further study:

1) Global Gaps

- *Long-term effects of global climate change* - There is insufficient understanding of cumulative, long-term effects of global climate change on hydropower generation potential and associated risk to dam safety in general worldwide.
- *Comparative Economic Viability* - More work is needed to develop robust, region-specific comparative studies of the economic viability of hydropower to other renewable energies (such as solar and wind), in order to make more informed power planning decisions.
- *Stakeholder Dynamics and Behavioural Risks* - Traditional risk models often do not fully understand stakeholder dynamics and the behavioural risk associated with these interactions. Further study is needed to understand how social and behavioural factors contribute to cost and time overruns.

[4] https://climate-diplomacy.org/case-studies/conflicts-surrounding-kishanganga-dam
[5] https://powerline.net.in/2020/08/10/green-rules/

2) Gaps Specific to the Indian Context:

- *Regional impact of climate change in India* - Though India has a large potential for hydropower and a strong hydropower development sector, there is little integrated research on the potential impact of climate change in terms of (specific) hydropower generation in various regions of India. Though it is argued that due to increased precipitation, the generation potential will increase in some parts of the country, there would be need for more detailed knowledge on regional variation and risk implications of extreme events (floods, droughts).
- *Adaptive Action Plan for Indian Hydropower* - Research on appropriate and effective adaptive strategies to 'climate-proof' Indian hydropower projects, in particular the specific cultural (Himalayan geology) conditions, is currently scant.
- *Context-specific risk assessment of the Himalayan area* - An effort needs to be made to develop and apply contextual risk assessment methods specific to the complications and uncertainties involved in hydropower development in the Indian Himalayas taking account of geological surprises, seismic activity and other natural hazards.
- *Probing the root causes and mitigation for overruns in India* - While cost and schedule overruns within India are well documented, more in-depth research is needed to identify the underlying causes and develop context-specific mitigation strategies to address India's unique challenges related to land acquisition, environmental clearances and stakeholder management.

Such knowledge gaps can therefore be addressed in a broader way through targeted research, so as to provide greater understanding of the challenges and for better informed, more effective risk management and mitigation strategies for hydropower projects, particularly in the Indian context.

III. SUMMARY AND TAKE AWAY FROM THE SLR

Hydropower is widely regarded as one of the most accessible and favored forms of renewable energy (Nautiyal and Goel 2020). The global capacity of hydropower is expanding at a significant pace. However, this swift growth is accompanied by various concerns that demand careful attention and cannot be overlooked. Hydropower projects are inherently location-dependent, requiring substantial capital investment and extended development timelines (Shaktawat and Vadhera 2021). The findings reveal that hydropower, while a crucial renewable energy source, are vulnerable to a wide array of uncertainties and risks, including but not limited to hydrological, geological, economic, environmental, social, regulatory, political, technological, financial, climatic, time and cost overrun risks, contract and claim related challenges (Mayeda and Boyd 2020). Additionally, the growing emphasis on sustainability has brought environmental and social concerns to the forefront of hydropower development (Peng, Shi, and Zhang 2021). Achieving sustainable progress in this sector now requires a careful balance between technological and economic advancement and environmental stewardship, through a meticulous planning and thoughtful system design to effectively address associated challenges (Huber 2019; Roger Gill 2023). Nevertheless, if the risks and challenges hydropower projects are confronted with, are not effectively studied and addressed in a timely manner, they are certain to cause distress in the project development including budget overruns and delays in project schedules (Sovacool, Gilbert, and Nugent 2014; Sovacool, Nugent, and Gilbert 2014). Consequently, this will postpone the delivery of electricity, increase its cost, and, in severe instances, cause complete project failure (Judith Plummer 2021; Plummer Braeckman et al. 2021).

Two major consequences of climate change, frequent flooding including GLOFs and fluctuations in river runoff, present serious challenges to hydropower projects (Chen and Lin 2018). While there are some conflicting findings by scholars with regard to generation potential, most of them confirmed that the dams (an essential component of hydropower development) are confronted with an enhanced risk of frequent flooding with increased magnitude (Dr Bernt Rydgren 2007; Giordano 2012). And this risk is even more hazardous as there was little knowledge on climate change at the time when most of existing dams were designed and built (Chen and Hossain 2019). This calls for adequate addressal for old dams as well as for new dams by revisiting the laid down procedure of selection of IDF besides other technological solutions. Literature review also highlights that geological surprises alongwith its complexity has remained a culprit for time overrun with associated cost overrun (Barton 2002; Indraratna, Soomro, and Rujikiatkamjorn 2021; Lee et al. 2018), (Naji et al. 2019). The complex geology of the Himalayas presents unique challenges, particularly in tunneling, due to the variable engineering geological conditions. In hydropower projects featuring extensive underground water conveyance systems that traverse diverse geological formations, achieving scheduled milestones can be particularly difficult due to the inherent uncertainties posed by geological risks (Petheram and McMahon 2019; Vn and Sudhakumar n.d.). Ensuring that tunneling activities are completed within the contractual timeframe requires thorough understanding of the geological setup (Lee et al. 2018; Mcwilliams n.d.).

This becomes even more crucial in turnkey projects, where fixed performance guarantees, defined completion milestones, and predetermined contract sums are in place (Vaishnava and Baka 2022). Any delays in construction can result in substantial financial penalties and additional costs for the contractor, creating significant pressure for the management team. Large-scale hydropower projects are often viewed as high-risk investments, which poses a significant barrier to securing funding, even for projects that are both technically sound and economically viable. This challenge is particularly pronounced in developing or underdeveloped countries, where limited access to electricity and inadequate generation capacity struggle to keep pace with rapidly increasing energy demands (Judith Plummer 2021; Plummer Braeckman et al. 2021). In developing and underdeveloped countries, the two most significant financial risks tied to large hydroelectric schemes are foreign exchange rates fluctuations and uncertainties within the electricity market (Markkanen, Braeckman, and Souvannaseng 2020). Stakeholder opposition to a project can significantly hinder its progress. This resistance often leads to delays and increased costs, driven by disputes and disagreements related to the project's design and execution (Olander and Olander 2007). Gaining a deep understanding of the underlying relationships amongst various stakeholders is essential to understand multi-organizational dynamics to enable project-participants to adopt effective cooperative strategies that optimize use of each stakeholder's resources (Wang et al. 2019).

This literature review has provided a critical and comprehensive analysis of the risks that frequently affect hydropower projects, examining both the global context and the specific challenges encountered in India while ferrying through valuable works done by number of scholars and underscores the importance of integrating these risks through the project developmental phases by their proper recognition, assessment and mitigation so that the aspirations of all involved stakeholders from project undertaken for implementation are fulfilled. This study also reveals that several gaps in knowledge persist, particularly concerning the long-term ecological and climatic impacts of hydropower, the role of stakeholder behavior, and the need for context-specific risk assessment and mitigation strategies, especially for regions like the Himalayas.

To improve the outcomes of hydropower projects, the implementation of effective mitigation measures and best practices is crucial. Globally, these include robust financial and technical risk management, comprehensive environmental and social impact assessments, proactive stakeholder engagement, and the utilization of advanced risk assessment tools. Strategies for managing cost and time overruns involve meticulous planning, adoption of advanced project management technologies, and effective contract management. In India, specific measures are needed to address the unique challenges, including streamlining clearance processes, adopting advanced geological surveying, strengthening local expertise, and implementing successful sediment management practices.

To support informed decision-making, it is essential that energy planners, investors, and other stakeholders remain aware of the risks associated with hydropower development. This comprehensive review of risks offers valuable insights for scholars by summarizing past academic work and outlining potential directions for future investigation in this area. To promote sustainable and successful hydropower development globally and in India, policymakers should prioritize the establishment of transparent and efficient regulatory frameworks, facilitate stakeholder engagement, and invest in research to address existing knowledge gaps. Developers and investors should adopt robust risk management practices, conduct thorough pre-project assessments, and embrace advanced technologies and methodologies for project planning and execution. Continued efforts and collaboration among all stakeholders are essential to mitigate the associated risks and overruns, ensuring their contribution to a secure and sustainable energy future. This approach will be particularly crucial for developing and underdeveloped nations.

IV. DISCUSSION

Managing time and cost overruns in hydropower projects demands a proactive, well-structured approach throughout the entire project lifecycle. Achieving this entails thorough planning, the implementation of strong risk mitigation measures, and maintaining clear, consistent communication with all relevant stakeholders.

A. Planning and Design Phase

The feasibility stage is an early phase in the project lifecycle where the viability of a proposed hydropower scheme is rigorously assessed. Key activities include detailed site investigations (geological, geotechnical, hydrological, seismic), environmental and social impact assessments, preliminary technical design of major components (dam, powerhouse, tunnels, etc.), initial cost estimation, risk identification, and the development of a preliminary project schedule.

Successful planning and design during this crucial stage are paramount for several reasons:

a) **Accurate Site Characterization Prevents "Geological Surprises":** Many hydropower projects, particularly those in mountainous regions like the Himalayas, involve extensive underground works (tunnels, caverns). Inadequate geological and geotechnical investigations during feasibility can lead to unexpected ground conditions (e.g., weak rock zones, high water ingress, unstable slopes) during construction. These "geological surprises" necessitate design changes, revised construction methods, and significant delays and cost increases, as seen in projects like the Parbati II and Subansiri Lower HEPs. Thorough investigation at the feasibility stage allows for a more accurate understanding of subsurface conditions, enabling realistic design and better risk mitigation planning.

b) **Inappropriate design during the planning stage:** A technically sound preliminary design based on comprehensive survey and investigation forms the basis for a good start of the project. Significant revisions during execution phases are results of firming up the design based on scanty and inadequate investigation. Such design variations have been found to be a common cause delays, change orders and cost escalations by various scholars. Conducting a thorough technical assessment during the feasibility stage, taking into account site-specific investigations helps establish a more dependable design foundation, thereby minimizing the likelihood of costly redesigns or revision in design during the execution phase.

c) **Comprehensive Risk Identification, Assessment and Mitigation:** Conducting a comprehensive risk assessment at feasibility stage enables the formulation of effective mitigation measures and contingency plans. Overlooking significant risks or inadequately addressing them, during the early stage of the project itself, carry the potential for severe disruptions and increased costs when the risks are encountered during project execution, as evidenced by the 2018 incident at the Ituango project.

d) **Reliable Cost Estimation and Financial Planning:** Initial cost estimates developed during feasibility are crucial for securing financing and making investment decisions and improper estimates prepared based on incomplete information will underestimate potential challenges, and they will inevitably lead to significant cost overruns in due course. Gaining a comprehensive understanding of the project scope, site-specific conditions, and associated risks enables more accurate and dependable cost estimations. This forms a stronger basis for financial planning and helps prevent the kind of substantial cost escalations observed in projects such as Diamer-Basha and Maheshwar.

e) **Realistic Scheduling Prevents Time Overruns:** Developing a achievable project schedule is highly dependent on an accurate understanding of the designed scope, estimated activity durations, and anticipated risks. When feasibility studies underestimate project complexity or overlook potential delays, the resulting timeline often proves overly optimistic. This can trigger missed milestones, contractual conflicts, and cascading delays throughout the project’s duration. Careful planning during the feasibility stage, accounting for foreseeable challenges and incorporating some cushions, supports the creation of a more achievable project schedule.

f) **Early Identification and Management of Environmental and Social Issues:** Hydropower projects frequently carry significant environmental and social consequences, including community displacement and impacts on local populations. Identifying these effects early and developing detailed resettlement, rehabilitation plans, and environmental management plans during the feasibility phase is particularly crucial. Failing to adequately address these concerns or neglecting meaningful engagement with affected communities from the project's outset can cause strong resistance, protests, legal challenges, and prolonged delays, as seen in the Maheshwar and Subansiri Lower projects.

In summary, even though unexpected challenges can still arise, a reliable feasibility study, built upon detailed, site-specific investigations covering technical, financial, social, and environmental aspects, is the critical foundation for reducing time and cost overruns in hydropower projects. Such a study enables a precise understanding of the site, facilitates realistic technical and financial planning, supports proactive risk mitigation, and ensures early attention to environmental and social issues, all of which are essential for preventing probable delays and budget excesses

B. Procurement and Contracting Phase

The contracting and procurement stage is a pivotal phase in the lifecycle of a hydropower project. It is during this stage that agreements are formalized with contractors, suppliers, and service providers who will be responsible for executing the project's design, construction, and equipment supply. Effective management of this stage is crucial because decisions made here directly influence the project's timeline, budget, and overall success, or conversely, contribute significantly to time and cost overruns.

Hydropower projects are complex and involve multiple specialized components and activities, from civil works (dam, tunnels, powerhouse) to hydro-mechanical and electro-mechanical equipment supply and installation. The selection of capable partners and the establishment of clear, robust contractual agreements are therefore essential mitigation measures against potential overruns.

Here are key mitigation measures during the contracting and procurement stage:

1) Developing Clear and Comprehensive Tender Documents: The foundation of effective procurement is well-defined tender documents. These should include:
- A precise scope of work, detailing all deliverables and responsibilities.
- Clear technical specifications for all civil, mechanical, and electrical components.
- Identification and allocation of risks between the owner and contractors.
- Detailed project schedules and milestones.
- Evaluation criteria that go beyond just the lowest price, considering technical capability, experience, financial strength, and proposed methodology. Ambiguity or incompleteness in tender documents can lead to disputes, change orders, and delays during execution.

2) Implementing Robust Pre-Qualification Criteria: Before inviting bids, a rigorous pre-qualification process is necessary to ensure that only technically capable and financially sound entities are considered. This involves evaluating potential bidders' past experience with similar projects, technical expertise, available resources (personnel, equipment), and financial stability. Awarding contracts to inexperienced or under-resourced contractors significantly increases the risk of delays and poor-quality work, leading to overruns.
3) Selecting Appropriate Contract Types: The choice of contract type should align with the project's characteristics and the level of risk the owner is willing to bear. Common types include:
- Lump-Sum/Fixed-Price Contracts: Suitable when the scope is well-defined and risks are clearly understood and allocated. They provide cost certainty for the owner but shift significant risk to the contractor.
- Cost-Plus Contracts: Used when the scope is uncertain. They offer flexibility but expose the owner to cost escalation risks.
- EPC (Engineering, Procurement, Construction) Contracts: A single contract for design, procurement, and construction. This can streamline coordination but requires a highly capable EPC contractor.
- Hybrid Models: Combining elements of different types. An inappropriate contract type can lead to disputes and financial disadvantages for either party when unforeseen events occur.

4) Effective Contract Negotiation: The negotiation phase is pivotal for finalizing key project aspects including terms, conditions, risk allocation, and pricing. When led by experienced professionals, effective negotiation ensures the resulting contract is equitable and clearly defines the responsibilities and entitlements of all parties. This clarity is crucial for minimizing the likelihood of future disputes that could otherwise cause delays and increase project costs.
5) Including Incentive and Penalty Clauses: Contract terms and conditions should incorporate provisions that encourage timely project completion and deter delays or underperformance. Including liquidated damages clauses can help compensate the project owner for financial losses due to postponed commissioning. Conversely, performance-based incentives, such as bonuses, can motivate contractors to meet or exceed schedule and quality benchmarks.
6) Establishing Clear Dispute Resolution Mechanisms: Even with thorough planning and good faith efforts, disputes may still occur during project execution. Therefore, contract conditions should explicitly define the procedures for resolving these conflicts, whether through negotiation, mediation, arbitration, or litigation. Establishing a clear and efficient dispute resolution mechanism is crucial for preventing minor disagreements from escalating into lengthy legal battles, thereby minimizing the risk of extended delays and additional costs.
7) Implementing Effective Contract Administration and Monitoring: Awarding the contract marks a key milestone, but it does not conclude the procurement process. Effective contract administration is crucial throughout the execution phase. This includes monitoring contractor performance, ensuring compliance with contractual obligations, managing changes or variations, and promptly addressing issues to prevent delays or cost escalations:
- Regular monitoring of progress against the schedule.
- Managing change orders efficiently and fairly.
- Ensuring compliance with technical specifications and quality standards.
- Effecting payments according to contractual terms and conditions.
- Maintaining clear communication channels. Poor contract management often leads to misunderstandings, causes delay in decision-making, and consequentially results in uncontrolled cost increases.

8) Considering Supply Chain Management: An essential precondition for complex infrastructure projects like hydropower plants is efficient supply chain management for the mobilization of materials and equipment. Logistics of transportation, production lead times, supplier dependability, and possible supply chain interruptions are all elements that procurement strategies need to

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take into consideration. The overall construction timeline may be significantly and permanently impacted by delays in the delivery of essential components.

By putting these mitigation techniques into practice during the contracting and procurement stage, project owners can create a strong contractual basis, work with qualified partners, and set up systems for efficient project management. By significantly lowering the chance of budget overruns and schedule delays, such actions increase the possibility that a project will be completed successfully and on time.

C. Construction and Implementation Phase

The construction and implementation phase marks the transition from planning to execution, where the designs and strategies developed in earlier stages are realized on the ground. This phase is typically the most resource-intensive in terms of both time and capital and is highly susceptible to disruptions that can lead to substantial delays and budget overruns. As such, implementing effective mitigation strategies during this stage is crucial to achieving successful project outcomes.

Hydropower construction entails intricate civil engineering tasks, the installation of large-scale mechanical systems, and the coordination of multiple stakeholders, often under challenging site conditions. To manage the inherent complexities and risks, proactive oversight and strong control mechanisms are essential in maintaining alignment with the project's planned timeline and financial targets.

Here are key mitigation measures during the construction and implementation stage:

1) Effective Project Management and Supervision: The designs and strategies developed in feasibility stage are put into practice on the ground during the construction and implementation phase, which signifies the change from planning to execution. Usually requiring the greatest amount of time and money, this stage is also the most vulnerable to interruptions, which can result in significant delays and cost overruns. As a result, successful project outcomes depend on the implementation of efficient mitigation strategies during this phase. Building hydropower requires complex civil engineering work, the installation of massive mechanical systems, and stakeholder coordination—often in difficult site conditions. Proactive supervision and robust control systems are necessary to manage the inherent risks and complexities while preserving alignment with the project's budget and schedule.
2) Robust Site Monitoring and Geological Risk Management: During excavation and construction, it is essential to continuously monitor the geological and geotechnical conditions, especially in areas that are vulnerable to unexpected subsurface conditions or ground instability. Risks like landslides, rock bursts, and tunnel collapses have historically impacted projects in geologically challenging environments. To mitigate these risks, it is crucial to implement appropriate ground support systems on time, use adaptive construction techniques informed by real-time data, and have knowledgeable geological personnel on site.
3) Quality Control and Assurance: Establishing a comprehensive quality control and assurance program is critical to ensuring that all construction activities and installed equipment comply with specified technical standards and requirements. Substandard workmanship can result in structural defects, equipment failures, and costly rework, ultimately leading to project delays and budget overruns. Regular inspections, rigorous material testing, and strict adherence to established quality management protocols are therefore essential components of effective project execution.
4) Schedule Management and Control: Careful planning of construction tasks, resource allocation, and continuous progress monitoring in relation to the initial timeline are all necessary for effective schedule management. Essential practices include identifying critical path activities, utilizing project management tools, and predicting potential delays. Frequent progress reports and thorough reporting make it possible to identify schedule deviations early on, enabling project teams to take swift corrective action and stop minor setbacks from turning into major delays and cost overruns. Furthermore, encouraging open communication among interested parties guarantees coordination and prompt scheduling problem solving.
5) Cost Control and Budget Management: To effectively track spending, manage cash flow, and make sure costs stay within the approved budget, a robust cost control system must be established. Clear procedures are crucial for handling change orders, regulating quantity variations, and ensuring that contractor payments correspond with finished work, according to industry best practices like those described in the Project Management Institute's PMBOK Guide and project management standards like ISO 21500. With the aid of tools like earned value management (EVM), regular financial reporting and forecasting make it possible to identify possible cost overruns early on and enable project managers to take swift corrective action. Enhancing overall financial oversight and facilitating informed decision-making throughout the project lifecycle are two benefits of integrating cost control measures with project scheduling and procurement activities.

6) Managing Environmental and Social Impacts during Construction: For project sites and the communities around them, construction activities frequently present significant environmental and social challenges. To properly address these issues, approved Environmental Management Plans (EMPs) and Resettlement and Rehabilitation (R&R) frameworks must be put into practice. These plans usually concentrate on lowering pollution, conserving local biodiversity, managing waste responsibly, and making sure that impacted or displaced communities are treated fairly and in accordance with the terms that have been agreed upon. Important mitigation strategies include habitat restoration, community engagement initiatives, noise and dust suppression measures, erosion and sediment control, and grievance redress procedures to quickly address issues. Comprehensive guidelines for managing these impacts are provided by international standards like the World Bank Environmental and Social Framework and the International Finance Corporation (IFC) Performance Standards. Community opposition may arise if these requirements are not followed.
7) Contingency Planning and Risk Response: Unexpected things can happen during the building phase, even with careful planning. It is essential to create clear contingency plans and quick response protocols for possible hazards like floods, accidents, or equipment failures in order to reduce their influence on project budgets and schedules. This strategy entails creating precise, workable emergency response procedures as well as setting aside funds for contingencies within the project's budget and timeline. Furthermore, frequent risk assessments and project team training improve readiness and facilitate prompt, well-coordinated responses to unanticipated events.
8) Supply Chain and Logistics Management: The timely delivery of the tools, supplies, and replacement parts needed for construction depends on efficient supply chain management. To guarantee that materials arrive on site on time, this necessitates proactive scheduling, careful supervision of transportation logistics, and close cooperation with suppliers. The construction timeline may be directly and negatively impacted by supply chain disruptions or delays, which may result in cascading delays across related activities. These risks can be reduced and consistent progress can be maintained by implementing tactics like just-in-time delivery, supplier performance monitoring, and contingency planning.
9) Health, Safety, and Security Management: Protecting the health and safety of workers and maintaining site security are critical priorities throughout the project lifecycle. Workplace accidents and security breaches not only risk injuries and fatalities but can also result in equipment damage and considerable project delays. To mitigate these risks, it is essential to enforce rigorous safety protocols, provide comprehensive training programs for all personnel, and ensure that the project site is secured against unauthorized access. Additionally, fostering a safety-first culture and conducting regular audits and emergency drills contribute to maintaining a safe and secure working environment.

Owners of hydropower projects can significantly enhance risk management, maintain stricter cost control, and more closely adhere to project schedules by consistently implementing these mitigation strategies during the construction and implementation phases. When taken as a whole, these proactive steps raise the project's chances of being completed successfully and on schedule.

D. Stakeholder Engagement

Establishing trust, resolving problems, and acquiring project approval all rely on early and frequent involvement of stakeholders, such as local residents, non-government organizations, and governmental agencies. Developing sound stakeholder relations involves, at the minimum, creating open communication channels, communicating information in advance and transparently, and making informed consideration of the project's social effects. To avert widespread opposition and minimize the chances of significant project delays, there is a need to actively resolve land and social issues like fair compensation and respectful resettlement practices.

E. New Trends and Technologies of Hydropower Project Management

Advanced project management techniques and technological innovation offer real-world solutions in managing cost overruns and schedule slips in hydropower projects. Predictive analysis, simulation, and monitoring of the project are being transformed through the growth in digitalization, including artificial intelligence (AI) and machine learning (ML). It makes management during the entire life of the project more precise and efficient. Real-time monitoring capabilities in digital solutions enable the detection of latent delays or budget drifts at an early stage, and artificial intelligence (AI)-powered analytics provide critical insights into project performance, facilitating immediate corrective action and proactive decision-making. Digital twins, virtual models of real-world systems and situations, are also applied to enhance project delivery and predict potential challenges.

One key emerging technology with the potential to significantly improve project quality is building information modelling, or BIM. BIM enhances design precision, facilitates early detection of conflict or inconsistency, and promotes enhanced collaboration among project teams through the creation of a comprehensive digital model of the project. Thus, it serves to reduce design faults, rework requirements, and cost and time overruns.

Increased capacity and scalable project deployment are possible with the deployment and configuration of modular power generation systems. When compared to customized solutions, these systems, which usually consist of prefabricated modules that are installed on the site, have the potential to significantly reduce construction time and cost.

Finally, more sophisticated and easier-to-use technology is being developed constantly in the area of project management software and tools, providing project managers sophisticated, user-friendly infrastructure for project planning, scheduling, cost management, and risk management capabilities. The smart tools allow for improved communication, collaboration and data-driven decision-making, resulting in quicker project delivery and fewer overruns.

V. CONCLUSION AND RECOMMENDATIONS

Time and cost overruns are unfortunately a perennial, endemic problem in the construction of hydropower projects around the globe. This paper has shown the sheer scale of interdependent causes of such overruns, ranging from embedded technical complexity and geology risk to environmental and social sensitivities and project management and contractual matters. Thematic discussion highlights the specific context nature of such concerns but also identifies common underlying drivers. The consequences of such overruns are extensive and have implications on financial sustainability, economic development, social well-being, and environmental sustainability. For this very important issue, a few suggestions can be proposed for different stakeholders:

1) For Researchers: It should be the objective of future studies to create more advanced risk assessment tools fitting the unique needs of hydropower projects. Advanced tools such as AI and machine learning must be integrated to enhance the cost estimation models. Comparison studies between different regions and project types, based on the effectiveness of different mitigations, would be a valuable addition to the topic.
2) For Practitioners in Industry: Active and coordinated management of the project should be there. This means investing in detailed feasibility studies and site investigation, sound risk management strategies at the beginning, and continuous early consultation with all the concerned parties, like the surrounding communities. Implementation of new technologies like BIM and computer-based project management systems should be for achieving efficiency and control. Providing fair and well-written contractual terms with efficient mechanisms for resolving conflicts also holds true.
3) For Policymakers: Governments and regulators should work to de-bottleneck hydropower project approval processes without relaxing robust environmental and social protections. Providing more transparency and accountability in project development by proper guidelines and monitoring mechanism is necessary. Facilitating good hydropower project management and sustainable development can also help prevent time and cost overruns.

The answer to the challenge of endemic cost and time overruns, to unlock the full potential of hydropower is a sustainable clean source of energy, is to fall into line with the strategy and best practice espoused in this review. Alignment by the hydropower sector to this will be revolutionary to the move towards more productive and efficient project delivery and making excellent progress towards delivering the vision for the sustainable energy future.

WORKS CITED

[1] A. Fashina, M. A. Omar, A. A. Sheikh, and F. F. Fakunle, “Exploring the significant factors that influence delays in construction projects in Hargeisa,” Heliyon, vol. 7, no. 4, Apr. 2021, doi: 10.1016/j.heliyon.2021.e06826.
[2] A. Huber, “Hydropower in the Himalayan hazardscape: Strategic ignorance and the production of unequal risk,” Water (Switzerland), vol. 11, no. 3, Mar. 2019, doi: 10.3390/w11030414.
[3] A. Kumar Patir, N. B. Choudhury, S. Roy, D. Choudhury, R. Thapa, and M. Khairujjaman Mazumder, “Impacts of the Lower Subansiri Hydroelectric Project, Northeast India, and Implications for Other Imminent Projects,” J. Himalayan Ecol. Sustain. Dev, vol. 18, 2023.
[4] Ansar, A., Flyvbjerg, B., Budzier, A., & Lunn, D. (2014). Should we build more large dams? The actual costs of hydropower megaproject development. Energy Policy, 69, 43–56.
[5] A. M. Ansari, D. R. Syed, and K. Ahmad, “STUDY ON THE CAUSES OF DELAY IN A CONSTRUCTION PROJECT AND RECOMMENDATION,” 2019. [Online]. Available: www.ijariie.com Asian Development Bank. (2010). West Seti Hydroelectric Project: Project documents and reports. Manila: ADB.
[6] Asian Development Bank. (2020). Punatsangchhu Hydroelectric Projects (Bhutan): Status update. Manila: ADB.
[7] A. Shaktawat and S. Vadhera, “Risk management of hydropower projects for sustainable development: a review,” Jan. 01, 2021, Springer Science and Business Media B.V. doi: 10.1007/s10668-020-00607-2.
[8] A. Srivastava and A. Misra, “Hydro-Energy Sector in India: A Review,” 2024. [Online]. Available: www.ijfmr.com
[9] Barton, N. 2002. Some New Q-Value Correlations to Assist in Site Characterisation and Tunnel Design. Vol. 39.

[10] Central Electricity Authority. (2022). Report on hydropower projects in India: Time and cost overruns. Government of India, Ministry of Power.
[11] Chen, Xiaodong, and Faisal Hossain. 2019. "Understanding Future Safety of DAMs in a Changing Climate." Bulletin of the American Meteorological Society 100(8):1395–1404. doi:10.1175/BAMS-D-17-0150.1.
[12] Chen, Yu, and Pengzhi Lin. 2018. "The Total Risk Analysis of Large Dams under Flood Hazards." Water (Switzerland) 10(2). doi:10.3390/w10020140.
[13] Debnath, S. (2025). "Climate Change, Unprecedented Floods, Dam Failures, Dam Hazzrds & Safety Aspects – An Indian Perspective" International Journal of Scientific Research and Engineering Development (IJSRED) ISSN : 2581-7175
[14] Debnath, S. (2025). "Contractual Fragility Its Fallout: Unpacking Delays and Cost Overruns in Indian Hydropower Projects" International Journal of Scientific Research and Engineering Development (IJSRED) ISSN : 2581-7175
[15] Debnath, S. (2025). "A comprehensive Investigation of Risks and Overruns in large Scale Hydro Power Projects and its mitigation: Focus on India" International Journal of Research and Analytical Reviews E-ISSN:2348-1269, P-ISSN:2349-5138
[16] Debnath, S. (2025). "The Silent Surge: Design Risks and Change Orders - Catalysts of Overruns in Hydropower Development" International Journal of Research and Analytical Reviews E-ISSN:2348-1269, P-ISSN:2349-5138
[17] Debnath, S. (2025). "Geological Factors Contributing to Delay and Cost Overruns in Indian Hydropower Projects: A Critical Review and Case-Based Analysis" International Journal of Research Publication and Reviews, ISSN 2582-7421
[18] Dr Bernt Rydgren. 2007. Addressing Climate Change-Driven Increased Hydrological Variability in Environmental Assessments for Hydropower Projects-a Scoping Study.
[19] EPM Colombia. (2019). Ituango Hydropower Project: Technical report on tunnel collapse. Medellín: Empresas Públicas de Medellín.
[20] Flyvbjerg, B. (2006). From Nobel Prize to project management: Getting risks right. Project Management Journal, 37(3), 5–15.
[21] Giordano, Thierry. 2012. "Adaptive Planning for Climate Resilient Long-Lived Infrastructures." Utilities Policy 23:80–89. doi:10.1016/j.jup.2012.07.001.
[22] Government of Pakistan. (2024). Diamer-Basha Dam Project: Revised cost and schedule estimates. Islamabad: Ministry of Water Resources.
[23] Huber, Amelie. 2019. "Hydropower in the Himalayan Hazardscape: Strategic Ignorance and the Production of Unequal Risk." Water (Switzerland) 11(3). doi:10.3390/w11030414.
[24] Indraratna, Buddhima, Mairaj Hyder Alias Aamir Soomro, and Cholachat Rujikiatkamjorn. 2021. "Semi-Empirical Analytical Modelling of Equivalent Dynamic Shear Strength (EDSS) of Rock Joint." Transportation Geotechnics 29. doi:10.1016/j.trgeo.2021.100569.
[25] International Hydropower Association. (2021). Hydropower status report: Sector trends and insights. London: IHA.
[26] J. S. Ramadhan and M. Waty, "Impact of Change Orders on Cost Overruns and Delays in Large-Scale Construction Projects," Engineering, Technology and Applied Science Research, vol. 15, no. 1, pp. 20291–20299, Feb. 2025, doi: 10.48084/etasr.9449.
[27] Japan International Cooperation Agency. (2011). Sondu-Miriu Hydropower Project completion report. Tokyo: JICA.
[28] Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. Journal of Financial Economics, 3(4), 305–360
[29] Judith Plummer, Braeckman. 2021. Perceptions of Risk in Relation to Large Hydropower Projects : A Finance Perspective. FutureDAMS.
[30] K. K. Panthi, "Evaluation of rock bursting phenomena in a tunnel in the Himalayas," Bulletin of Engineering Geology and the Environment, vol. 71, no. 4, pp. 761–769, Nov. 2012, doi: 10.1007/s10064-012-0444-5.
[31] Lee, Jaekook, Hafeezur Rehman, Abdul Muntaqim Naji, Jung Joo Kim, and Han Kyu Yoo. 2018. "An Empirical Approach for Tunnel Support Design through Q and RMi Systems in Fractured Rock Mass." Applied Sciences (Switzerland) 8(12). doi:10.3390/app8122659.
[32] M. Aslam, E. Baffoe-Twum, and F. Saleem, "Design Changes in Construction Projects – Causes and Impact on the Cost," Civil Engineering Journal (Iran), vol. 5, no. 7, pp. 1647–1655, Jul. 2019, doi: 10.28991/cej-2019-03091360.
[33] Markkanen, Sanna, Judith Plummer Braeckman, and Pon Souvannaseng. 2020. "Mapping the Evolving Complexity of Large Hydropower Project Finance in Low and Lower-Middle Income Countries." Green Finance 2(2):151–72. doi:10.3934/GF.2020009.
[34] Mayeda, A. M., and A. D. Boyd. 2020. "Factors Influencing Public Perceptions of Hydropower Projects: A Systematic Literature Review." Renewable and Sustainable Energy Reviews 121.
[35] M. R. Nezami, M. L. C. de Bruijne, M. J. C. M. Hertogh, and H. L. M. Bakker, "Inter-Organizational Collaboration in Interconnected Infrastructure Projects," Sustainability (Switzerland), vol. 15, no. 8, Apr. 2023, doi: 10.3390/su15086721.
[36] M. Debasish Mishra, M. Pragyan Priyadarshini, and A. Professor, "The Key to Successfully Implementing Sustainable and Socially Responsible Construction Management Practises : A Project Feasibility Analysis".Mcwilliams, M. J. n.d. Geological Risk Design for Risk Management.
[37] Mcwilliams, Mike J., L. V Kumar, A. S. Wain, and C. Bhat Sida. n.d. Uri Hydro-Electric Project, India: Evaluation of the Swedish Support.
[38] Mevada, Jay, and Ganesh Devkar. 2017. Analysis of Reasons for Cost and Time Overrun in Indian Megaprojects.
[39] Naji, Abdul Muntaqim, Muhammad Zaka Emad, Hafeezur Rehman, and Hankyu Yoo. 2019. "Geological and Geomechanical Heterogeneity in Deep Hydropower Tunnels: A Rock Burst Failure Case Study." Tunnelling and Underground Space Technology 84:507–21. doi:10.1016/j.tust.2018.11.009.
[40] Nautiyal, Himanshu, and Varun Goel. 2020. "Sustainability Assessment of Hydropower Projects." Journal of Cleaner Production 265.
[41] Olander, Stefan, and Stefan Olander. 2007. "Stakeholder Impact Analysis in Construction Project Management." Construction Management and Economics. doi:10.1080/01446190600879125.
[42] Pakistan Water & Power Development Authority. (2019). Neelum–Jhelum Hydropower Project: Progress and challenges. Islamabad: WAPDA
[43] Peng, Shengping, Guoqing Shi, and Ruilian Zhang. 2021. "Social Stability Risk Assessment: Status, Trends and Prospects —a Case of Land Acquisition and Resettlement in the Hydropower Sector." Impact Assessment and Project Appraisal 39(5):379–95. doi:10.1080/14615517.2019.1706386.
[44] Petheram, C., and T. A. McMahon. 2019. "Dams, Dam Costs and Damnable Cost Overruns." Journal of Hydrology X 3:100026. doi:10.1016/J.HYDROA.2019.100026.
[45] Plummer Braeckman, Judith, Sanna Markkanen, Pon Souvannaseng, Plummer Braeckman, and S. Souvannaseng. 2021. Mapping the Evolving Complexity of Large Hydropower Project Finance in Low and Lower-Middle Income Countries Citing This Working Paper.
[46] PWC. 2014. Hydropower in India Key Enablers for a Better Tomorrow. www.pwc.in.
[47] PwC. 2017. Accelerating Hydropower Development in India for Sustainable Energy Security. www.pwc.in.

[48] R. K. Choudhary, S. Dubey, and M. K. Lakra, “Treatment of collapsed faces of hydraulic tunnels passing under natural stream with low cover - A case study of Teesta-VI hydroelectric project (500 MW) in Sikkim (India),” in Tunnelling into a Sustainable Future – Methods and Technologies, CRC Press, 2025, pp. 3685–3692. doi: 10.1201/9781003559047-469.
[49] R. Müller and R. Turner, “The Influence of Project Managers on Project Success Criteria and Project Success by Type of Project,” European Management Journal, vol. 25, no. 4, pp. 298–309, Aug. 2007, doi: 10.1016/j.emj.2007.06.003.
[50] S. Vaishnava and J. Baka, “Unruly Mountains: Hydropower assemblages and geological surprises in the Indian Himalayas,” Environ Plan E Nat Space, vol. 5, no. 3, pp. 1123–1145, Sep. 2022, doi: 10.1177/25148486211050780.
[51] T. Subramani, P. S. Sruthi, and M. Kavitha, “Causes of Cost Overrun In Construction,” 2014. [Online]. Available: www.iosrjen.org
[52] X. Hu and Y. Chen, “IMPACT OF BIM ON PROJECT PERFORMANCE.”