Project Management Update from Nepal[1]

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Nepal's Hydropower Landscape: Strengths, Vulnerabilities, and Growth

1. Introduction:

Nepal is home to one of the richest hydrological systems in the world, that provide significant opportunities for hydropower development. The country's rugged landscape and its rivers, which originate in the Himalayas, create ideal conditions for harnessing hydroelectric energy. Given the rising concerns about climate change and global energy supply issues, hydropower emerges as not only a clean and renewable energy option but also a key player in ensuring energy sustainability and economic growth.

The benefits of hydropower are numerous. It requires very little fuel, produces low greenhouse gas emissions, has lower operational costs, and lasts a long time, making it a sustainable and economically sound energy solution. From small-scale micro-hydro installations that bring electricity to isolated rural areas to large utility plants that support national grids and even export energy, Nepal’s potential for hydropower spans a wide range of technologies and locations, leading to significant improvements across various sectors.

This report provides an in-depth analysis of Nepal’s hydropower industry, outlining the current situation, major ongoing projects, and the broader factors influencing the nation’s

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development. It examines both recent successes and the challenges posed by geopolitical changes, as well as environmental and technical issues.

2. Nepal's Hydropower Landscape:

The electricity sector in Nepal mainly relies on hydropower, with approximately 90% of its energy generated by run-of-river (RoR) plants. These systems harness the natural flow of rivers and require little to no storage, which suits the country's mountainous landscape and its commitment to renewable energy development.

Out of Nepal's estimated 83,000 MW theoretical hydropower capacity, approximately 43,000 MW is considered economically viable. Yet, as of 16 July 2025, only 175 operational hydropower plants, representing a combined licensed capacity of 3,388.744 MW, have been commissioned (Department of Electricity Development (DOED), 2025). This substantial underdevelopment highlights a persistent gap between potential and realization. In response, the Government of Nepal has intensified its hydropower development efforts to meet surging domestic demand and to capitalize on regional electricity trade opportunities. According to the DoED, 259 additional hydropower projects, amounting to 10,691.546 MW in total capacity, are currently under construction or awaiting financial closure. In addition, hydropower projects with a combined capacity of 17,000 MW are under consideration either in the feasibility stage or awaiting government approval for Power Purchase Agreements (PPAs).

Hydropower's dominance in Nepal's energy mix is both a strategic strength and limitation. The monsoon season (June to September) yields high river flows, allowing them to generate excess power and become temporarily energy surplus. On the other hand, the dry season (December to March) is characterized by low river discharge, leading to generation shortages and increased reliance on electricity imports. During these periods, Nepal imports electricity from India to meet up to 25% of it's peak demand.

Seasonal variability in water flow has been further exacerbated by climate change. Erratic hydrological patterns and extreme weather events increasingly disrupt electricity generation. In September 2023, excessive rainfall led to significant damage at the 456 MW Upper Tamakoshi Hydropower Project, making it non-operational for several months. Similar incidents have caused annual production deficits, at times reducing output by up to 40% relative to forecasts.

Domestic energy demand has been rising rapidly. Daily peak consumption has surged to approximately 2,000 MW, a sharp increase from just 300 MW a decade ago. Per capita electricity consumption, once among the lowest globally, has risen to around 400 kWh and is targeted to reach 1,500 kWh by 2030. To meet this demand, the government aims to add 900 MW of new generation capacity to the grid, bringing the national total to approximately 4,500 MW.

Simultaneously, Nepal is leveraging surplus generation capacity for regional exports. Long-term power trade agreements have been signed with India, while power exports to Bangladesh have commenced via Indian transmission corridors. Last year, Nepal Electricity Authority (NEA) reported exporting 1.94 billion kWh, an average of around 700

MW, to India, making Nepal a net electricity exporter for the first time. By late 2024, India approved an additional 251 MW of imports from Nepal, bringing the total approved export volume close to 1,000 MW. Bangladesh also began importing 40 MW via Indian interconnections, and its long-term energy roadmap envisions sourcing up to 9,000 MW from Nepal by 2040.

While there has been some improvement, Nepal's grid infrastructure still faces significant challenges. The limited transmission capacity is a major hurdle, especially during the peak monsoon season, when over 100 MW of generated power is often not utilized. Because of poor grid connectivity, around 20 hydropower projects have been unable to deliver electricity, resulting in an estimated loss of USD 21 million. High transmission and distribution losses combine these challenges. To overcome these issues, it is essential to make strategic investments in high-voltage transmission lines, grid automation, and load management systems. The national budget emphasizes the importance of these efforts, laying out plans for expanding the grid and implementing energy storage solutions to effectively distribute excess electricity during periods of high demand and enhance export potential.

Nepal’s ambitions are substantial. The government aims to increase installed generation capacity to 10,000 MW by 2026 and reach 28,500 MW by 2035. Cross-border electricity trade is a foundation of this vision. Nepal already exports over 450 MW to India under bilateral agreements, and momentum is growing for integration with Bangladesh, which further positions Nepal as a major clean energy exporter in the region.

Currently, Nepal’s hydroelectric development is characterized by underutilized potential, seasonal production variability, modest installed capacity (approximately 3.3 GW), and critical infrastructure shortages. Large, economically viable hydropower sites remain largely undeveloped. The sector comprises a diverse mix of stakeholders, including state-owned enterprises, joint ventures, and Independent Power Producers (IPPs). While major infrastructures, such as the Upper Tamakoshi and Tanahu Hydropower Projects, are under NEA and its subsidiaries, many RoR plants are implemented by IPPs.

3. Regulatory and Institutional Framework:

Nepal’s hydroelectric projects operate within a complex regulatory ecosystem. The foundational laws are the Water Resources Act (1992/93) and the Electricity Act (1992), which set the stage for development. The DoED, under the Ministry of Energy, Water Resources and Irrigation (MoEWRI), issues survey, feasibility, and construction licenses as well as approve PPAs. The Electricity Regulatory Commission (ERC) is the independent regulator for tariff-setting and licensing oversight. It approves PPAs and tariffs for both domestic sales and export and oversees project PPAs and wheeling agreements.

The primary development agencies are the state-owned NEA and the Investment Board Nepal (IBN) for mega projects. NEA handles the operation of national grid and generation of its own projects. It also formed several subsidiary companies to build large dams (e.g. Upper Tamakoshi, Tanahu, and Upper Arun). IBN manages investment proposals and Public-private Partnerships (PPPs) for strategic large projects (over 500 MW). The

government's Hydroelectricity Investment and Development Company Ltd (HIDCL) provides co-financing and equity. The Water and Energy Commission Secretariat (WECS) provides long-term planning, such as national water plans and environmental flow guidelines.

- **Incentives and PPAs:** Hydroelectric Policy 2001 and later rules introduced a generation-based royalty and prioritized a portion of power for local/domestic use. Earlier policies implemented fixed Feed-in Tariffs for projects under certain sizes and currencies. Today most large PPAs allow purchase in local currency with inflation adjustment; some export PPAs involve foreign currency (USD) pricing. The ERC has recently moved to harmonize PPA terms to attract investment: for example, standardizing the escrow and guarantee requirements. The Electricity Trade Act (1996) and subsequent treaty with India create a framework for cross-border energy exchange. In practice, energy trade is moving under negotiated agreements (e.g. tripartite power sales agreement with India's NTPC-VVN for Bangladesh export). Export transactions to India currently use high-voltage links (e.g. 400 kV Dhalkebar-Muzaffarpur) managed by NEA and India's PGCIL, with contracted export volumes up to 600 MW.

- **Environmental and Social Regulations:** All hydroelectric projects in Nepal are required to obtain Environmental Impact Assessment (EIA) clearance from the Ministry of Environment. Under the Environment Protection Act and EIA regulations, developers must address resettlement needs, ensure fish migration pathways, and compensate for affected forests and infrastructure. To meet these obligations, projects submit Environmental Management Plans and Resettlement Action Plans as part of the approval process. Oversight bodies such as the Electricity Development Board and environmental tribunals are authorized to enforce compliance with prescribed mitigation measures. In practice, local opposition, especially against large reservoirs and river diversions, has led to delays in projects like Budhi Gandaki and the Kaligandaki diversion. To improve local acceptance and reduce conflict, developers are adopting more stringent approaches, which include promises for forest conservation and sharing royalties with the local populace.

- **Grid and Market Administration:** NEA maintains the national grid and buys output from IPPs. To improve transparency, NEA recently launched online systems (Central Information Portal) for bidding and consumer information. The new Grid Code and a draft Transmission System Operator law are intended to open the market gradually. However, NEA remains the single buyer for now. The Finance Ministry and central bank also play roles in approving foreign loans and guarantees for projects.

In recent years, Nepal's institutional framework has rapidly expanded to meet the surging demands. Yet there are some gaps: the ERC is still building capacity to regulate all PPPs, and there is no specialized body for managing electricity exports across borders. Coordination among agencies (DoED, NEA, ERC, local governments) can be challenging. Rules for public-private partnership and foreign investment create avenues

for funding, but regulatory and policy uncertainty are the risks. Recent World Bank (WB) and Asian Development Bank (ADB) analyses emphasize the need to strengthen these institutions and develop clear sector laws. For example, the regulatory infrastructure is being upgraded; Nepal's 2022-2030 energy strategy has endorsed a robust tariff regime and power trading framework to improve investor confidence. Such reforms are critical to support the large-scale hydropower projects.

4. Key Projects

Nepal's hydroelectric development is based on several major projects, from the recently completed plants to ambitious multi-gigawatt schemes being planned. Below we highlight key projects focusing on scale, status, and management innovations.

- **Upper Tamakoshi (456 MW, cascade project, RoR)**: Completed in 2021, this run-of-river project on the Tamakoshi River is Nepal's largest commissioned plant. Built by a Chinese-Nepali consortium, it was financed by concessional loans and NEA equity. The earth-and-rockfill dam and four Pelton turbines provide 10% of Nepal's total capacity. From a management viewpoint, Upper Tamakoshi was notable for extensive rock excavation and its integration into NEA's cascade system (it supplies water downstream to a series of smaller plants). However, it also highlights risk: In September 2024 a landslide destroyed its intake de-sander and control room. The plant was offline for more than 3 months and only fully resumed by mid-2025. This event highlighted the importance of climate-resilient design and rapid-response maintenance plans.

Upper Tamakoshi Project (456 MW), Nepal's largest operational hydropower plant, remains a symbol to the sector's potential (Photo: Upper Tamakoshi Hydropower Limited)

- **Tanahu (140 MW, storage-type):** Under construction on the Marshyangdi River, Tanahu is a storage (reservoir) project being implemented by NEA. Work has proceeded in phases: in early 2023 the main access tunnel (436 m long) was completed, enabling transport of materials for the 140m tall dam and intake structure. Construction is split into packages (dam by a Vietnam-Nepal Joint Venture, power complex by Sinohydro of China). The project is targeted for

completion by mid-2026. Tanahu's PPA illustrates how Nepal manages power purchases: NEA signed to buy dry-season power at NPR 12.4/kWh (about 9 cents) and monsoon power at NPR 6.08/kWh. The staggered completion and tariff structure provide lessons in phased execution and demand-risk allocation. Tanahu has faced typical challenges: construction delays (e.g. a brief halt in 2022 due to a shortage of explosives for tunneling) and complex supply chain.

A 3D Model of Tanahu Hydropower Project (140 MW) (Photo: Tanahu Hydropower Limited)

- **West Seti (750 MW, storage-type)**: After decades of delay, the West Seti hydropower project is advancing under a contract awarded in late 2024 to NHPC Limited (India) by the Investment Board of Nepal. Originally conceived in 1994 and revived through a 2022 MoU and updated Detailed Project Report, the project involves constructing two 185-meter-high concrete dams and an underground powerhouse with four 187.5 MW turbines, totaling 750 MW and generating an estimated 3,636 GWh annually. As a complex mega-project, it involves layered financing, likely a mix of NHPC equity, international investment, and multilateral guarantees, and requires renewed environmental and social plans, along with cross-border coordination for grid integration and export arrangements to India. Previous setbacks due to local opposition have made stakeholder engagement a central task, but the recent contract award reflects progress in addressing long-standing institutional and legal obstacles.

- **Upper Arun (1,061 MW, RoR)**: As Nepal's largest planned hydroelectric project, Upper Arun is being developed by a subsidiary of the NEA (Upper Arun Hydroelectric Limited) and is currently in the pre-construction stage, with construction targeted to commence in 2026. Designed as a RoR system, the plant will divert water from the Arun River via an 8.5 km tunnel to an underground powerhouse. With an estimated cost of $1.71 billion, the World Bank has agreed in principle to lead an international financing consortium, potentially contributing up to $550 million. The project includes the construction of a 400 kV transmission line to integrate with the national grid. Recognized as a "Game Changer Project,"

this project aims to provide affordable energy generation along with a reliable energy supply. Its implementation utilizes cutting-edge project management techniques, such as Building Information Modeling (BIM) and the creation of a digital twin. These strategies are designed to improve collaboration, minimize data silos, and streamline the delivery process throughout various project phases. The project is scheduled for completion and operation by 2033. Upper Arun exemplifies a modern infrastructure delivery model, blending digital engineering, international collaboration, and a long-term strategy to strengthen Nepal's energy export capacity and economic trajectory.

Upper Arun Hydropower (1061 MW) Project Location (Photo: Upper Arun Hydro-electric Limited)

- **Dudhkoshi (635 MW, storage-type)**: The newly prioritized Dudhkoshi reservoir project, located on the Dudhkoshi River, has gained momentum with substantial support from the ADB, which in March 2024 approved a $580 million package, including a $30 million grant, in collaboration with the World Bank. Designed to complement the Upper Arun project in eastern Nepal, Dudhkoshi will feature a large seasonal storage dam to stabilize power output throughout the year. Significantly, the feasibility studies also explore a 200 MW pumped-storage component, highlighting an adaptive approach that integrates future energy storage capacity with generation. Technical and environmental assessments are still underway, with disbursement linked to compliance with safeguard requirements. Dudhkoshi illustrates a coordinated model of financing and early-stage sustainability planning, aligning with international standards and demonstrating a forward-looking approach to multipurpose infrastructure development.

- **Budhi Gandaki (635-1,200 MW, storage-type)**: Budhi Gandaki, cited in national strategy documents, has seen various proposals over the years, ranging from an initial 635 MW design to the more recent 1,200 MW target mentioned in the national budget speech. The project has faced persistent delays due to disputes over resettlement and environmental impact, with more than 14,000 households

identified as affected in earlier assessments. There's a growing interest in financial planning, but the project is still pending its final licensing approval. Budhi Gandaki emphasizes the challenges involved in overseeing major infrastructure projects, especially when it comes to securing community consent, conducting thorough environmental assessments, and establishing revenue-sharing agreements with local authorities. Given the project's size, it requires significant funding, which will probably need the involvement of multilateral lenders, along with effective strategy to engage stakeholders and address issues around resettlement and the livelihoods of those affected. The key lesson here is the importance of fostering trust from the beginning by ensuring inclusive participation and transparent benefit-sharing to avoid the social resistance that has previously affected progress.

- **Middle Marsyangdi (69 MW) and other small RoR plants**: As standard examples, Nepal has dozens of smaller plants built by local firms or cooperatives. Middle Marsyangdi (68.8 MW) was finished in 2008 as a cascade project; others like Chilime (22 MW) and Modi A (14 MW) illustrate effective PPPs in the sector. Many small projects use international turbines but rely on domestic construction. From a management perspective, these projects have helped develop local engineering capacity. They also typically feature fixed-rate PPAs indexed to fuel prices, demonstrating Nepal's approach to mitigating tariff risk for investors.

- **Pumped Storage Hydropower Projects (PSHPs):** Recognizing seasonal mismatch, Nepal's authorities have compiled an inventory of pumped-storage opportunities (see "Opportunities" section below for details). These are coupled with large reservoir sites or conceived as stand-alone projects. While not yet built, the planning of pumped storage demonstrates adaptive project planning: it extends project benefits by storing monsoon energy for peaking and export. These projects will require expertise in both civil works and power system optimization - another illustration of Nepal's evolving project capacities.

- **Other Significant Projects:** The government's budget outlines plans to initiate major projects such as Sunkoshi III (783 MW), Nalagad, Jagdulla, and Naumure multipurpose hydropower schemes, alongside dozens of smaller hydro projects. An example of this is Sunkoshi III, a dam project that is currently in its early development phase in Sindhupalchok district. These initiatives illustrate Nepal's strategic move towards developing larger reservoir-based infrastructure that serves multiple purposes, including generating electricity and providing irrigation support. Ambitious projects like the Sapta Koshi High Dam and the Pancheshwar Multipurpose Project, jointly planned with India, represent the upper tier of this expansion, though they remain distant from actual implementation. From a management perspective, such projects demand strong inter-sectoral coordination across energy, agriculture, and disaster management domains, extended timelines for planning and construction, and, for transboundary ventures, careful diplomatic engagement.

Nepal's hydroelectric project portfolio ranges from small run-of-river plants to large-scale storage dams, reflecting a broad and evolving energy strategy. Significant milestones include the completion of Upper Tamakoshi in 2021, the commissioning of Middle Marsyangdi in 2023, and the 2024 contract signing for West Seti. Projects such as Tanahu and Dudhkoshi have now moved into the construction and financing stages. Ongoing international collaboration is a key aspect of these developments, involving multilateral funding entities like the World Bank and the ADB, as well as contractors from India, China, and Europe. There are regional partnerships with countries like India and Bangladesh. This global participation adds new dimensions to how projects are managed, including the oversight of international contracts, adherence to global safety and environmental standards, and the coordination of cross-border energy infrastructure. The implementation of advanced technologies, such as BIM, along with an enhanced focus on corporate social responsibility, indicates that Nepal's hydropower sector is aligning with international best practices in planning, execution, and engagement with local communities.

5. Opportunities

The hydroelectric sector in Nepal presents a wealth of opportunities for project managers and policymakers to explore.

- **Untapped Hydro Potential:** The considerable difference between Nepal's hydropower potential, estimated at 43,000 MW, and its current installed capacity of about 3,300 MW presents a tremendous opportunity for growth. With electricity demand anticipated to reach 60,000 GWh by 2030, scaling up generation capacity is critical. There are several key projects on the pipeline, such as Upper Arun, Budhi Gandaki, and Sunkoshi III, which could significantly increase capacity and provide consistent baseload power if managed efficiently. It's essential to strategically plan these initiatives to focus on sites that offer both reliable geotechnical conditions and high energy production. Smaller hydro options like micro and mini projects can be quickly implemented to improve rural electrification and support off-grid communities, enhancing the overall national strategy.

- **Pumped Storage:** The development of pumped-storage systems presents an opportunity to revolutionize Nepal's energy sector. This technology allows the conversion of excess electricity into a form that can be dispatched as needed, enhancing the flexibility of the power grid and facilitating energy exports during high-demand periods. The NEA has identified 156 potential sites where 33 are being prioritized for their combined capacity of 42,000 MW. Even the successful implementation of just a few projects, like the 332 MW Syarpu or the 1,596 MW Hulingtar-Dukim, could improve the overall stability of the energy system. These facilities would enable the storage of energy generated in wet seasons for use during dry seasons when demand typically spikes or during times when market prices are favorable for exporting to India. While the initial costs for these projects can be high, global experiences show that pumped storage can yield long-term advantages in terms of reliability, pricing, and integration of renewable energy sources. Given its mountainous landscape, Nepal is especially well-positioned for

such projects. To advance this sector, it will be necessary to tap into climate finance, concessional loans, and mixed funding strategies that align with international decarbonization goals. If approached thoughtfully, pumped storage could become a key player in Nepal's energy export strategy and enhance the country's domestic energy security.

- **Regional Electricity Trade:** Nepal's access to regional electricity markets has expanded, with over 600 MW now exported to India under formal agreements. Bangladesh has joined as a new buyer, importing 40 MW during the 2024 monsoon and targeting up to 9,000 MW by 2040. These developments present strong incentives for scaling up hydropower and investing in cross-border infrastructure. Transmission planning must prioritize compatibility with neighbouring systems, particularly India's 400 kV grid, and involve operational coordination. Export PPAs, especially those denominated in hard currency, enhance financial viability and attract investment. However, India's post-2018 policy excludes imports from Chinese-funded or constructed projects, requiring Nepal's developers to carefully manage financing sources and partnerships. Long-term opportunities lie in regional energy market integration. Projects like the Butwal-Gorakhpur interconnection and alignment with India's day-ahead power market are critical. Realizing this potential will require institutional reform. A technically sound, independent regulatory authority must lead tariff-setting using transparent, cost-based models. Depoliticized governance will be key to maintaining investor trust and guiding the energy transition in a stable, strategic direction.

- **Finance and Partnerships:** The participation of development partners is crucial for the advancement of Nepal's hydropower industry. Both the World Bank and the ADB have made significant commitments: ADB has allocated a loan of $580 million for the Dudhkoshi project, while the World Bank is planning to invest $500 million into the Upper Arun project. These combined efforts align with Nepal's energy transformation goals within a framework focused on "Green, Resilient, and Inclusive Development," allowing project teams to tap into concessional financing and benefit from international technical expertise. Interest from the private sector is also growing, with Indian companies like NHPC and SJVN, as well as Chinese firms such as Sinohydro and CWE, playing active roles in the market. Nepal's regulations permit foreign investments of 25-33% through permits, which creates opportunities for crucial equity influx. However, an obstacle remains in designing agreements that effectively balance government assurances with the financial considerations necessary to attract institutional investors. While the local capital markets are still in their early stages of development, there are promising initiatives underway, such as the potential to list large projects or issue bonds, which could help mobilize local investment.

- **Technology and Innovation:** Modern management approaches provide significant potential to enhance project performance across Nepal's hydropower sector. At Upper Arun, technologies like BIM and digital twinning have reduced

design errors and improved collaboration among various teams. Advanced tools like drones and LIDAR technology allow for quick terrain assessments for feasibility studies, reducing the timeline from months to just days. Major equipment suppliers, including GE and Andritz, are offering solutions to optimize turbine performance. For projects in remote areas, telemonitoring systems and IoT sensors enhance safety and streamline maintenance processes. Moreover, the integration of renewable energy sources opens up exciting opportunities. For instance, coupling hydropower with solar energy can help manage seasonal fluctuations by providing electricity even during dry or windy conditions. The ambitious Green Hydrogen Policy in Nepal further builds on this vision by investigating the use of excess hydropower for hydrogen production, which could benefit various industries, including fertilizers and transportation. Altogether, employing grid storage, hybrid renewable systems, and digital project management techniques has the potential to significantly enhance the returns on investments in hydropower sector.

- **Socio-Economic Benefits:** Well-planned hydroelectric projects can enhance local economies by creating jobs and improving critical infrastructure, including roads and bridges. When stakeholders are properly engaged, these projects can raise the overall quality of life within communities. The Nepalese government requires developers to invest in community development programs, such as schools, healthcare facilities, and irrigation systems. Establishing clear revenue-sharing approaches, such as providing royalties to the districts affected and setting up dedicated support funds, helps build trust and positive relationships. Furthermore, the income generated from exporting excess electricity can further assist in achieving broader national development objectives. Although these benefits might not be immediately evident, they are crucial for promoting sustainable project environments and facilitating future approvals. Project managers who prioritize early and genuine community involvement can turn social impact from a potential challenge into a strategic benefit.

- **Environmental and Climate Co-Benefits:** By focusing on hydropower as a renewable energy source, Nepal plays a crucial role in regional efforts to lower carbon emissions. Generating electricity from hydro sources replaces the need for fossil fuels, both within Nepal and in neighboring countries that rely on imported power. This shift opens up opportunities for carbon financing through initiatives like the UN Clean Development Mechanism or emerging carbon credit systems designed for large-scale run-of-river and reservoir projects. This effort supports Nepal's ambitious goal of achieving net-zero emissions by 2045. Also, hydro projects that adhere to social and environmental standards can provide essential benefits for climate adaptation, such as controlling floods during the monsoon season and providing irrigation during droughts. For example, reservoir dams can help reduce flooding downstream and ensure water supply resilience. Incorporating strong environmental protections in project designs can improve access to 'green' financing options, which often come on better terms and help further sustainable development goals.

Nepal's hydroelectric industry is at a pivotal moment filled with remarkable potential. The country has abundant natural resources that have yet to be fully utilized, along with a growing appetite for energy, active regional markets, and solid support from development partners. This landscape offers project managers a plethora of opportunities, including numerous projects, readily available funding, and the chance to implement cutting-edge technologies. However, the main challenge is to turn these advantages into tangible results while effectively managing the intricate technical, environmental, and geopolitical elements that influence the success of projects.

6. Challenges

Although there are plenty of opportunities, hydropower projects in Nepal face several challenges that require careful management. From the initial planning stages to operations after the project has been commissioned, a variety of risks must be managed to achieve successful results.

- **Geographical and Technical Risks:** Nepal's rugged terrain poses significant challenges for hydropower projects. The steep valleys and high-altitude sites make access difficult, and the unpredictable nature of the rock formations can cause major delays, as seen in the construction of the 436-meter tunnel at Tanahu. Further complicating matters is the region's seismic risk, as evident in the aftermath of the devastating earthquakes in 2015. This highlights the critical need for earthquake-resistant designs for dams, powerhouses, and transmission lines. Landslides are another concern, especially during periods when rivers are diverted for construction. The 1980 Seti landslide serves as a critical reminder of these risks, emphasizing the importance of thorough geotechnical assessments. During the monsoon season, rivers can carry substantial sediment, which can quickly wear down turbines and reduce the usable life of reservoirs. To address this, effective sediment management strategies, including de-sanders and adjustments to operations, are necessary. The extreme cold and remote settings of many sites introduce challenges related to worker safety and logistics, such as the difficulty in transporting heavy machinery along narrow mountain roads and managing health risks associated with high altitudes.

- **Climate and Hydrological Risks:** Climate change has transitioned from a impending concern to an immediate reality, bringing increased uncertainty to hydropower projects. The impacts are significant, with altered monsoon cycles and extended droughts potentially decreasing annual energy production by 30-40%. Furthermore, the risks posed by Glacial Lake Outburst Floods (GLOFs) have escalated, presenting serious threats to Nepal's infrastructure. The recent destruction of Rasuwagadhi border highway, caused by a sudden glacial lake collapse upstream in Tibet, resulted in significant human and financial losses, including damage to a 200 MW hydropower facility. Such occurrences highlight the vulnerabilities of both run-of-river and storage projects, especially when their design relies on outdated hydrological data. Floods can overwhelm dam structures or damage intake systems, as demonstrated by the earlier events at Upper Tamakoshi. As hydrological patterns evolve, it’s crucial to reassess infrastructure

continuously, redesign spillways to handle extreme water discharge, adjust construction schedules to accommodate unpredictable monsoon periods, and shift long-term investment strategies towards storage and pumped-storage solutions to manage surplus flows during drier months. For developers and decision-makers, this scenario demands a heightened focus on hydrological modeling, the integration of climate scenario planning at every phase, and the agility to adjust ongoing projects as observed conditions deviate from past patterns.

- **Environmental and Social Challenges:** Large hydropower projects often require extensive changes to land and water use, which can have a significant impact on local communities and ecosystems. For example, the Budhi Gandaki project has historically necessitated the relocation of thousands of residents, while the West Seti project faced opposition due to concerns over displacement. Non-governmental organizations and community groups frequently highlight issues such as deforestation, the decline of fisheries, which are important for the livelihoods of many people living along the river, and the overall health of river ecosystems. Addressing these challenges calls for effective engagement with all stakeholders to ensure compliance with environmental standards and secure community support. Project teams are generally responsible for creating Resettlement Action Plans and facilitating public consultations as part of their EIA obligations. Ignoring these crucial steps can lead to substantial delays, as shown by the cancellation of West Seti's previous license in 2011 following public protests. Successful projects prioritize hiring qualified social specialists, promote transparent sharing of benefits through community development initiatives and job creation, and respond quickly to concerns raised by community members. Furthermore, adhering to strict social and environmental guidelines set forth by international funding organizations like the World Bank and the ADB adds another level of complexity to project implementation.

- **Regulatory and Political Risks:** Nepal's ever-changing political landscape creates obstacles for energy projects. Throughout the years, shifts in policy, such as changes to subsidy programs and tariff regulations, have created uncertainty. Moreover, bureaucratic delays are a frequent issue, as many projects face prolonged waits for construction permits and EIA approvals. Although there is a statutory limit of one year for obtaining licenses, backlogs within the DOED continue to be an issue, complicated further by a lack of clear coordination among key government agencies, including the MoEWRI, the Ministry of Federal Affairs and General Administration, and the Ministry of Finance. A recent decision by the Supreme Court prohibits hydropower projects in protected regions, such as national parks and wildlife preserves, putting around 300 proposed developments at risk and highlighting the judiciary's influence on these matters as well as the delicate nature of the Himalayan ecosystems involved. The lack of a specific regulator for electricity exports means that cross-border agreements with India are often determined through inconsistent negotiations. While Nepal's legal framework for hydropower seems to be quite thorough, the fragmented

governance coupled with recent judicial and regulatory developments adds multiple layers of uncertainty to the progression of energy projects.

- **Financial and Economic Risks:** Hydroelectric projects require substantial capital investment, and Nepal's relatively small economy presents challenges related to local currency availability and foreign exchange exposure. Large foreign currency borrowings, often in USD, create significant debt servicing obligations. The NEA's financial health plays a crucial role, as its position as the sole power purchaser affects lender confidence and financing terms. Given NEA's historical financial vulnerabilities, tariff floors are negotiated to reassure project sponsors of reliable payments. Currency risk is managed through NEA guarantees that allow conversion of USD PPAs into NPR payments if necessary. Rising costs for key materials like steel, cement, and fuel can inflate project budgets, Tanahu's initial $505 million estimate, for example, may increase amid price surges. Fluctuating interest rates further impact financing expenses. To address these risks, projects build in contingency funds, favor fixed-price construction contracts when feasible, and enforce strict procurement oversight. International agencies such as the IFC recommend financing diversification, combining concessional loans with private equity, and employing risk mitigation tools like political risk insurance and partial risk guarantees.

- **Contractual and Execution Risks:** Managing hydropower projects involves navigating a complex landscape of contractors and suppliers. A setback in one area, like tunnel excavation, can delay other parts of the project, such as dam construction, creating a chain reaction that affects the entire project timeline. It's crucial to enforce strict quality control, as errors in reinforced concrete or mechanical systems can lead to expensive rework and prolonged project schedules. The participation of international firms adds further complexity, requiring expert construction management to overcome language barriers, cultural differences, and varying operational standards. Disruptions in the supply chain can introduce more challenges. For example, the Tanahu project faced a temporary shortage of explosives, necessitating careful planning due to Nepal's stringent blasting regulations. Seasonal weather conditions also play an important role in construction timelines. Monsoon rains typically halt major river diversions and civil engineering work, forcing most activities into a limited dry season, which can extend overall project durations. To mitigate these risks, project planning should incorporate effective strategies, enhanced by modern techniques like Earned Value Management (EVM), highlighting a growing focus on disciplined and data-driven execution methods.

- **Grid and Market Risks:** Once hydropower plants are operational, they rely on a dependable grid for transmitting the electricity. If upgrades to the transmission infrastructure are delayed, it can force power generators to scale back their output, leading to operational challenges. Currently, the 400 kV Dhalkebar line is crucial for transferring power between Nepal and India, but it is facing limitations in capacity. Future projects need to coordinate with plans for expanding

transmission, such as linking electricity generation from Tanahu to the Bharatpur substation. On the market side, if domestic demand fails to keep up with projections, expected exports may fall short, affecting revenues for the projects. Nepal has set an ambitious target to export 2,000 MW by 2030, which relies on having adequate generation capacity as well as stable international markets. Challenges also stem from the unpredictability of India's purchasing policies, particularly restrictions on projects involving Chinese entities, which could leave some Nepali hydropower assets without buyers. To counter these risks, developers typically enter into long-term PPAs that include clear volume commitments and protective measures, such as rights to step in or terminate the agreement, to protect the interests of all stakeholders involved.

- **Sustainability and Environmental Risks:** Large-scale reservoir projects can significantly disrupt river ecosystems and contribute to greenhouse gas emissions due to decaying vegetation. To manage such projects effectively, it is crucial to maintain environmental flows downstream, provide fish passages or bypass channels when necessary, and address deforestation issues through reforestation. Ignoring these aspects could lead to opposition from various stakeholders, both at home and abroad. The seasonal release of surplus energy, often exceeding 100 MW, not only represents a missed opportunity for utilizing clean energy but also highlights weaknesses in the planning of the energy system. Incorporating complementary renewable sources, like solar and biogas, can help diversify Nepal's clean energy landscape and improve the resilience of the overall system. Current efforts, such as the plan to dedicate 100 MW to solar energy, demonstrate an increasing awareness of the benefits of an integrated approach.

- **Local Community Challenges:** In addition to land acquisition, maintaining positive community relations with the local community presents its own set of challenges. Issues like labor disputes, including strikes and safety concerns, have occasionally slowed down construction projects. It’s crucial to manage local expectations, particularly regarding misunderstandings, such as the belief that nearby residents will see reduced electricity bills. This requires open and ongoing communication. Navigating these dynamics involves both risks and opportunities; if approached with respect, engaging stakeholders can turn potential issues, like protests or work stoppages, into avenues for community support and improved productivity. Therefore, having clear communication strategies and benefit programs tailored to local needs is vital for effective project risk management.

Nepal's hydroelectric sector is operating with considerable uncertainty, which forces project managers to identify and manage risks at every stage - from analyzing water resources and designing engineering solutions to engaging stakeholders and overseeing contracts. There's a growing trend towards adopting internationally recognized project management practices, such as PMI methods and FIDIC-based contracts. Multilateral lenders now require Environmental and Social Management Plans (ESMPs) and detailed assessments of construction-related risks.

Due to the complicated relationships among technical, financial, social, and environmental challenges, it's crucial to have a comprehensive and regularly updated risk management strategy in place. The International Finance Corporation (IFC) suggests mapping out the interests of various stakeholders, including workers and investors, and creating specific strategies to address their concerns. Major projects like the Upper Arun project are making progress by using BIM to reduce design errors, implementing climate resilience measures, and setting up escrow accounts to protect payments. However, with the sector's rapid growth, many projects, especially those led by smaller IPPs, still lack effective risk management. To tackle this issue, there's an urgent need for capacity building through training, embracing global standards, and promoting a culture of continuous learning.

7. Future Prospects

Looking ahead, Nepal's hydroelectric sector has a number of encouraging trends and strategic goals:

- **Major Growth Targets:** The government has set an ambitious long-term energy strategy that aims to achieve an installed capacity between 25,000 and 28,000 MW by the mid-2030s, with hydropower being at the heart of this expansion. This goal represents a massive increase from the current capacity of 3,300 MW to over 20,000 MW within the next decade. Hydropower remains a central focus for the fiscal year 2025/26, as indicated by budget allocations for major projects such as Budhi Gandaki (1,200 MW), Dudhkoshi (635 MW), and Upper Arun (1,061 MW). The short-term objective for FY 2025/26 is to add 942 MW to the national grid, bringing the total installed capacity to about 4,800 MW. If these projects are executed successfully, they could transform Nepal's energy generation landscape by 2030.

- **Diversification and Clean Energy Mix:** Although hydropower will continue to dominate Nepal's energy system, there is a strong commitment to diversify the energy sources. The country's Nationally Determined Contributions (NDC) and development strategies highlight the importance of integrating solar, wind, and bioenergy along-with hydropower. This approach will promote hybrid energy systems, allowing solar installations to generate power during the day while also alleviating demand on the grid at night. Diversifying the energy mix increases resilience to climate impacts, offering alternative outputs during droughts that may affect hydropower. For project managers, this approach implies that future hydropower developments will likely include renewable energy elements, like solar panels on reservoir surfaces or wind measurement devices on dam infrastructures, leading to more adaptable and robust energy systems.

- **Grid Modernization and Integration:** Nepal is making progress in improving its power infrastructure through focused grid upgrades. Key projects include expanding the 400 kV and 132 kV transmission systems, with potential plans for High-voltage Direct Current (HVDC) lines to facilitate long-distance electricity exports. There are also pilot initiatives using smart grid technology, featuring

remote monitoring and adaptive protective measures. The inclusion of demand-side management tools and new battery storage technologies (in conjunction with pumped hydro) is being explored. Over the next decade, the idea of a "smart hydroelectric grid" is expected to play a crucial role in Nepal's energy strategy. Projects that invest in grid integration, such as transmission infrastructure and Flexible AC Transmission Systems (FACTS), are likely to enhance both operational and financial results. There are plans to construct 732 km of double-circuit transmission lines as part of this expansion, along with several bilateral transmission corridors to boost electricity trade with neighboring countries. Key projects include the Butwal–Gorakhpur, Inaruwa-Purnia, and Chameliya-Jaulbibi lines, all of which are supported by ongoing diplomatic efforts to expand Nepal's access to regional electricity markets.

- **Regional Cooperation:** Nepal is making significant efforts to strengthen its energy partnerships within South Asia. Landmark agreements, such as the electricity sales deal with Bangladesh, are creating pathways to third-country markets. Ongoing discussions with Bhutan, another hydroelectric exporter, and Indian grid operators are aimed at forming a South Asian power trading network. If successful, this network would allow Nepal to trade or store electricity across borders, providing exciting opportunities for flexible power management. As a result, it's crucial for project managers to understand international grid standards and regulatory frameworks for cross-border operations. Considering that climate impacts and hydroelectric resources cross national lines, Nepal's hydropower projects are set to become integral components of a larger regional system.

- **Climate Adaptation and Resilience:** Nepal is highly vulnerable to climate change, and its ambition to achieve net-zero emissions by 2045 requires sustainable development of hydropower projects. Future installations must be "climate-proof" meaning they should be built to withstand floods, GLOFs, and changing rainfall patterns. A significant part of this strategy will focus on enhancing storage capabilities and integrating pumped storage systems. It's also crucial to maintain environmental flows and implement effective watershed management to keep river basins healthy. To achieve this, effective project management must incorporate the latest climate science and utilize adaptive strategies, such as updating reservoir operation protocols in response to changing climate data. Securing donor funding will depend on resilience planning to support these objectives.

- **Innovation and Technology Adoption:** Future hydropower projects in Nepal are set to adopt global best practices more extensively. For example, the Upper Arun project is already using BIM and digital twinning, which sets a high standard for future projects. Other innovative technologies, like real-time data analytics for tracking plant performance, 3D geotechnical modeling, and lean construction methods, will also become more prevalent. There are also opportunities to integrate battery storage with hydropower systems and to explore green hydrogen production. Hydrogen fuel can be generated by using affordable hydroelectric

power during periods of high-water flow. The country's hydrogen policy reflects its commitment to these developments. Overall, these improvements will enhance project designs, speed up timelines, and create greater benefits for stakeholders.

- **Institutional and Policy Maturation:** To ensure the continuous growth of its hydropower sector, Nepal needs to strengthen its institutional capacity. The ERC must be fully staffed to manage the increasing workload effectively. Public organizations like the NEA, HIDCL, and IBN are working to streamline their processes to better oversee projects from approval to operation. The Ministry of Finance is currently developing credit-rating frameworks for the NEA, which will help reduce borrowing costs. There's also a growing interest in listing NEA's subsidiaries on the stock exchange to diversify ownership. Enhancing transparency through online license auctions and improved project monitoring dashboards will be essential. These reforms will facilitate access to financing and help lower overall project costs.

- **Social Development Integration:** Looking ahead, Nepal is dedicated to making sure that hydropower development generates real benefits to local communities. There are plans for community development projects, focusing on infrastructure, education, and healthcare improvements near project sites. As the sector evolves, it is expected that stronger social management frameworks and gender inclusion programs, such as promoting women's leadership in energy, will emerge along with closer collaborations with local governments. Gaining public support will be crucial for future projects, leading project managers to prioritize effective engagement with stakeholders throughout all phases, from initial planning to the final handover.

Nepal's hydroelectric sector is looking toward a bold and complex future. If current efforts succeed, the country could become a key player in renewable energy, not just locally but across South Asia as a whole. The national approach, evident in its policies and budgetary focus, highlights water resources as a central component of economic growth while also acknowledging the associated risks. To realize this ambitious vision, it will be essential to maintain high standards in project management. This involves combining engineering, finance, environmental care, and community involvement into a cohesive strategy. Given the global emphasis on climate actions and the transition to clean energy, Nepal's commitment to hydropower is both timely and strategic. Achieving success will require careful planning, the implementation of best practices, and the ability to adapt to the evolving challenges.

8. Conclusion

Nepal's hydroelectric industry is currently at a crucial juncture, filled with vast untapped resources and an urgent need to expedite development. Although the country has abundant water resources, only a small portion has been turned into usable energy. The increasing demand for electricity at home, along with promising opportunities for exports in South Asia, has prompted both government and industry stakeholders to accelerate the implementation of projects.

Successful project delivery requires careful planning, precise execution, and adaptable oversight. One critical aspect is coordinating construction with the monsoon season to avoid weather-related delays. Engaging effectively with government agencies, private sector developers, and local communities is crucial to preventing disputes and setbacks. The use of digital tools like BIM, real-time monitoring, and data analytics enhancing decision-making and ensuring greater transparency in operations.

On the financial front, developing hydropower in Nepal is expensive and involves navigating a complicated mix of concessional loans, public-private partnerships, and currency risks. It is essential to structure blended financing, manage debt sustainability, and secure power purchase agreements that cater to both local and export demands to ensure financial health.

Sustainability has become an integral part of the project landscape. Modern hydropower initiatives now include environmental protections, comprehensive resettlement plans, and mechanisms for sharing social benefits. These measures not only satisfy regulatory requirements but also transform potential conflicts into opportunities for greater community involvement and support.

International partnerships play a crucial role in making projects feasible. Collaborations with organizations like the World Bank, ADB and various bilateral donors have bolstered both technical and financial assistance. As countries like India and Bangladesh seek clean energy imports, Nepal is in a strong position provided that its legal, technical, and compliance frameworks align with regional standards.

However, climate variability presents additional challenges, pushing the focus toward storage-based hydropower and resilient infrastructure. Adapting project designs is becoming increasingly important to ensure stable energy generation and mitigate long-term risks posed by changing water patterns.

For professionals in the field, Nepal serves as a real-world example of how to manage large-scale infrastructure projects within a complex landscape. Insights from ongoing projects highlight the need for strong procurement practices, proactive risk management, and governance that prioritizes community involvement. Building both technical and institutional capacities will be vital for sustained progress.

As Nepal endeavors to turn its water resources into a reliable source of energy security and economic growth, success will depend on disciplined execution, inclusive collaboration, and a long-term vision. The groundwork is being laid, but realizing these ambitions will require stakeholders to transition from fragmented efforts to a unified approach towards a regional energy future.

9. Declaration of Use of Generative AI

The author utilized Grammarly and ChatGPT during the drafting of this report to refine complex or unclear sentences, with the goal of enhancing clarity, precision, and grammatical accuracy. Following the use of these tools, the author conducted a thorough

review and made necessary edits. The final content is the result of the author's judgment, and full responsibility is assumed for its accuracy and integrity.

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Yamanta Raj Niroula is an accomplished Project Management Professional with more than 17 years of rich experience in engineering, infrastructure development, and project management across a variety of global settings. His skill set includes project planning, procurement, contract management, stakeholder engagement, and risk management, all with a particular emphasis on delivering projects in remote and developing areas under challenging conditions.

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