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Analysis of Surplus Hydropower Generation Potential in Nepal by Fiscal Year 2087/88

by

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CERTIFICATE OF APPROVAL

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a dissertation entitled "**Analysis of Surplus Hydropower Generation Potential in Nepal by Fiscal Year 2087/88**", submitted by **Shahadev Thapa** in partial fulfillment of the requirement for the award of the degree of **Master of Science in Power System Engineering.**

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ABSTRACT

Nepal is endowed with an enormous renewable energy potential estimated at approximately 72,544 MW, encompassing a diverse mix of hydropower, solar, wind, and other renewable resources. Despite this abundance, only about 5% of the total potential has been harnessed to date, with hydropower contributing more than 95% of the national electricity generation. This heavy reliance on hydropower underscores the urgent need for diversification of the generation mix and integration of flexible technologies to ensure grid reliability and operational adaptability.

Over the past decade, Nepal has undergone a transformational shift from a prolonged power deficit to an electricity-surplus nation. The Power Purchase Agreement (PPA) records indicate a pipeline of 11,436 MW of renewable energy projects under various stages of development, positioning Nepal as a strategic partner in regional Cross-Border Electricity Trade (CBET). However, in the medium term, cross-border transmission line (CBTL) pose a significant challenge, restricting Nepal's ability to fully trade its surplus generation. This constraint risks energy curtailment during the wet season, leading to substantial revenue losses from underutilized surplus power.

This study adopts a quantitative approach to estimate Nepal's surplus energy potential and cross-border trade prospects for the target year FY 2087/88. Using an Excel-based analytical model, hourly generation and demand profiles for Run-of-River (RoR), Peaking Run-of-River (PRoR), Storage, and Solar schemes were projected in a 24 hour time slots for each month. The generation scheduling for PRoR and Storage plants was optimized based on Day-Ahead Market (DAM) price signals to maximize revenue from cross-border electricity trade during both wet and dry seasons. The analysis considered a projected 9,290 MW of generation capacity comprising 59% RoR, 26% PRoR, 13% Solar, and 3% Storage hydropower. Zoning of INPS reveals that Zone 1 (Koshi, Madhesh, and Bagmati Provinces) accounts for 68% of generation, while Zone 2 (Gandaki, Lumbini, Karnali, and Sudurpaschim Provinces) contributes 32%, with corresponding CBTL capacities of 1900 MW and 2,100 MW respectively under N-1 contingency condition.

The findings indicate that approximately 17.5 TWh of annual surplus electricity will be available in the Integrated Nepal Power System (INPS) by FY 2087/88, equivalent to an annual revenue potential of NRs 113 billion under price-based dispatch.

However, due to transmission constraints, nearly 1.03 TWh of potential wet-season generation may require curtailment, resulting in an estimated annual revenue loss of NRs 4.66 billion. The study, therefore, recommends the timely completion of high-voltage cross-border transmission projects, including the Inaruwa–Purnea and Lamki–Bareilly 400 kV corridors, to enhance export capacity and minimize economic losses.

Furthermore, the integration of Pumped Storage Hydropower (PSH) into the INPS significantly enhances system flexibility and economic performance. By storing surplus solar and RoR energy during low-price hours and generating during high-price periods, PSH enables effective energy shifting for price optimization. The integration of proposed combined capacity of 928.5 MW PSH increases annual exportable energy to 18.64 TWh and boosts total revenue to NRs 127.68 billion, a 12.6% improvement over operation without PSH. Therefore, this study concludes that with the integration of PSH, optimized market-responsive generation scheduling, and timely transmission infrastructure development, Nepal can effectively transform its hydropower surplus into high-value regional exports. These measures will strengthen Nepal's position as a clean energy hub in South Asia, ensuring both energy security and sustainable economic growth by FY 2087/88.

Keywords: Surplus, CBET, Cross Border Transmission Line (CBTL), Transmission Bottlenecks, PSH, Hydropower

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LIST OF ABBREVIATIONS

CBET Cross Border Electricity Trade

CBTL Cross Border Transmission Line

NEA Nepal Electricity Authority

IEEE Institute of Electrical and Electronics Engineers

DAM Day Ahead Market

TWH Terawatt-hour

INPS Integrated Nepal Power System

COD Commercial Operation Date

DOED Department of Electricity Development

LDC Load Dispatch Center

RCOD Required Commercial Operation Date

AF Availability Factor

PSH Pump Storage Hydropower

CHAPTER ONE: INTRODUCTION

1.1 Background

Nepals hydropower sector represents one of the most dynamic and rapidly evolving energy systems in South Asia, distinguished by its exceptional natural endowment, significant recent achievements, and vast future potential. The countrys transition from a state of chronic energy scarcity to a position of emerging generation surplus has fundamentally reshaped its national energy trajectory and created new opportunities for sustainable development, regional energy cooperation, and economic growth.

Geographically, Nepal is a landlocked country located between two major economies India to the south and China to the north. Despite its modest size, Nepal possesses extraordinary renewable energy resources. According to the Water and Energy Commission Secretariat [1], the nations theoretical hydropower potential stands at approximately 83,000 MW, of which 42,133 MW is considered technically and economically feasible. This potential is primarily distributed across the Koshi, Narayani, Karnali, and Mahakali river basins [2]. The estimated 83,000 MW represents around 2.27% of global hydropower potential, concentrated within just 0.1% of the worlds land area. This ratio places Nepal among the most hydropower rich nations globally, comparable to countries such as Norway, Switzerland, and Bhutan in terms of per capita renewable resource endowment.

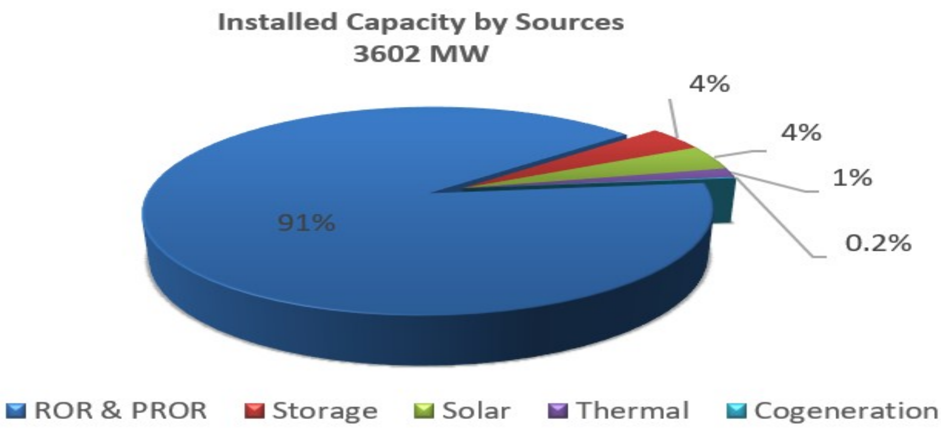

Figure 1.1: National Install Capacity by Sources

Hydropower has historically been the backbone of Nepals electricity generation. Figure 1.1 represents current install capacity of Nepal. As of 2025, it contributes over

95% of the countrys 3,605 MW of total installed capacity [3], marking a remarkable rise from 830 MW in 2014. The addition of 463 MW in recent FY 2023/24 alone demonstrates the sectors accelerating growth momentum. The existing generation mix comprises approximately 95% hydropower (3,404 MW), 4% solar (141 MW), 1.5% thermal (53 MW), and 0.2% co-generation (6 MW). While hydropower remains dominant, there is growing recognition of the need to diversify the national energy portfolio for enhanced system reliability. Other renewable resources particularly solar and wind still remain largely untapped despite their vast potential. Solar energy has an estimated potential of 432 GW, while wind power resources are projected to exceed 3,000 MW (AEPC, 2025) if these resources are explored in full extent. Consequently, Nepals power system remains one of the cleanest in world, with per capita emission reported of less than 0.53 tons per person [4].

In the past decade, Nepal faced severe electricity shortages, particularly during the dry season.Period between FY 2064/65 and 2072/73 marked an acute energy crisis, with insufficient generation capacity failing to meet rising demand [5, 6]. Load shedding during this period reached up to 18 hours per day, severely affecting industrial productivity, commercial operations, and household welfare. In FY 2071/72, power imports accounted for over 75% of NEAs total electricity sales revenue, leading to annual economic losses estimated at NRs 11.8 billion [5]. This crisis underscored the structural vulnerabilities of a hydropower system dependent on seasonal inflows and the need for diversified and reliable energy development.

To eliminate the chronic electricity crisis and harness Nepal's hydropower potential, the government have introduced "National Energy Crisis Reduction and Electricity Development Decade (2016-2026) with two parallel strategies. The first was rapid acceleration of hydropower development through streamlined approvals, attractive public-private partnership models, and targeted investments in large reservoir and run-of-river projects to boost domestic generation. Concurrently, major investments were made in strengthening the national transmission and distribution network, including the construction of high-capacity cross-border transmission lines, to reliably deliver the increased power, end load-shedding, and establish a foundation for regional energy exchange and export [7].

The period from FY 2076/77 to FY 2081/82 marked a transformation phase in Nepals power sector. Policy reforms, institutional strengthening, improved regulatory mechanisms, and substantial public private investments contributed to an unprecedented acceleration in project implementation. The commissioning of flagship projects such as Upper Tamakoshi (456 MW) symbolized a shift toward national self sufficiency. The total operational capacity of 3,330 MW, contributed by approximately 170 projects interconnected with the Integrated Nepal Power System (INPS), reflects a robust and diverse project portfolio. The size distribution of projects indicates that about 15.8% have capacities below 10 MW, 19.5% are in the 1025 MW range, 43.2% in the 25100 MW range, and 21.4% exceed 100 MW [8] . In terms of generation technology, approximately 75% are run-of-river (RoR) plants providing base load generation, 20% are peaking run-of-river (PRoR) plants contributing to peak-hour supply, 4% are solar projects, and 5% are storage-type hydropower plants capable of seasonal energy regulation. This mix reflects a hydropower-driven development strategy that aligns with Nepals environmental priorities and sustainable development goals.

The spatial distribution of generation capacity reveals dense cluster in the central region (42.2%), owing to proximity to major load centers and easy accessible to transmission infrastructure, while the eastern and western regions contribute approximately 21.5% and 36.3%, respectively [8]. However, this pattern is gradually shifting as grid connectivity expands, making remote hydropower sites more economically viable.

In recent years, Nepal has successfully transitioned from a power-deficit to a power surplus nation. As of 2025, projects totaling 10,675 MW are under development at various stages, out of which 7,805 MW have signed Power Purchase Agreements (PPAs) with the NEA [9]. This rapid growth presents Nepal with a unique opportunity to utilize its renewable energy surplus not only for domestic consumption but also as an export commodity enhancing economic resilience and strengthening regional cooperation through Cross Border Electricity Trade (CBET) [10].

To harness these developments strategically, the Government of Nepal (GoN) has formulated the Energy Development Roadmap and Action Plan [11]), targeting a generation capacity of 28,500 MW by 2035, including 15,000 MW for export. The Roadmap also emphasizes major transmission expansion proposing 6,431 circuit km of 132 kV, 4,061 circuit km of 220 kV, and 6,440 circuit km of 400 kV lines to strengthen grid reliability and export capability.

Cross-border electricity trade is a central component of Nepals long-term power sector vision. The countrys trading relationship with India has matured, with access to both short-term markets and long-term bilateral frameworks. Nepal currently exports around 1,000 MW of power to India and has signed a commitment for India to import up to 10,000 MW over the next decade. Nepal also participates in Indias Day-Ahead Market (DAM) and Real Time Market (RTM) through the Indian Energy Exchange (IEX). Moreover, a tripartite agreement signed in October 2024 between NEA (Nepal), NVVN (India), and BPDB (Bangladesh) has enabled the export of 40 MW electricity to Bangladesh via the Indian grid, marking Nepals entry into multilateral energy trade under the BBIN and BIMSTEC regional frameworks. Such developments signify Nepals growing role as a regional clean energy hub.

In this context, the present thesis seeks to evaluate Nepals medium-term hydropower generation potential and its cross-border trading opportunities by FY 2087/88. The research aims to quantify the surplus hydropower energy available for export through an analytical framework integrating generation modeling, demand projection, and market scheduling analysis. By examining Nepals renewable resource base, evolving policy and market environment, and regional energy cooperation dynamics, this study aims to provide strategic insights for optimizing hydropower utilization and strengthening cross-border electricity trade. The outcomes are expected to inform policymakers, planners, and energy developers in advancing Nepals vision of becoming a regional renewable energy exporter within the South Asian power corridor.

1.2 Problem Statement

Nepals hydropower sector has undergone a remarkable transformation over the past decade, shifting from a state of chronic energy deficit to one characterized by emerging energy surpluses. The countrys installed generation capacity has grown more than 2.5 folds within a short span increasing from 1,451 MW in 2021 to 3,600 MW in 2025. According to the Department of Electricity Development [3] and NEA [12], the present capacity has reached approximately 3,605 MW, with hydropower contributing nearly 95 percent of total generation.

About 494 number of projects are currently in the development pipeline, with combined capacity of 11,436 MW have already signed Power Purchase Agreements (PPAs) and are expected to achieve commercial operation (COD) in the coming years. Alongside this rapid hydropower expansion, diversification of the national energy mix is gradually emerging, marked by increasing participation and investment in solar power projects.

The recent trend of power generation, as illustrated in Figure 1.2, indicates that national generation has already begun to surpass the countrys peak demand. If all planned projects are commissioned as scheduled, this trend is expected to accelerate in the near future, potentially leading to a situation where generation capacity far exceeds domestic demand. While such progress in hydropower development is commendable, it also exposes a critical seasonal imbalance in the system. More than 90% of the existing and upcoming hydropower plants are of the Run-of-River (RoR) and Peaking Run-of-River (PRoR) types, which generate surplus electricity in the wet season and experience significant production drops during the dry months.

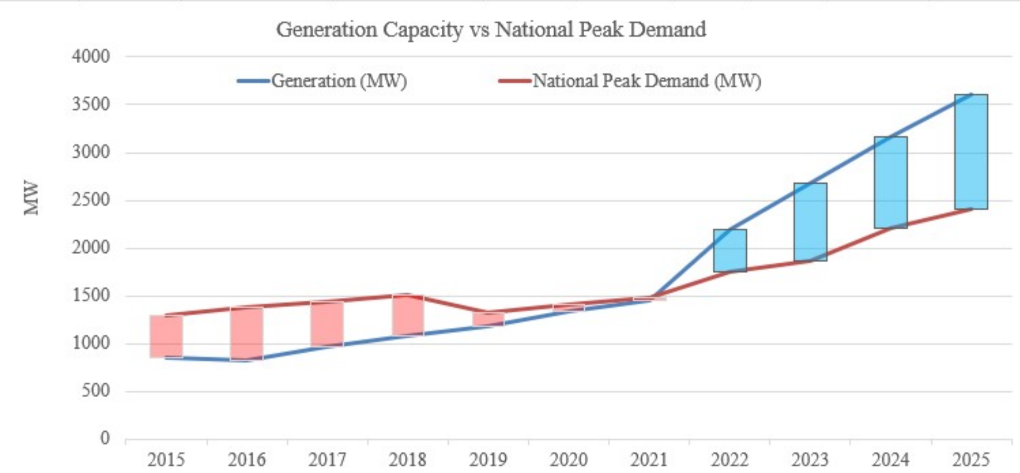

Figure 1.2: Generation Capacity and National Peak Demand Trend

This seasonal variability poses operational and financial challenges. During the wet season, excess energy that cannot be consumed domestically or exported will need to be curtailed, resulting in energy spill. Such curtailments have direct economic consequences for the NEA, as the utility remains obligated to pay for the contracted energy under Take-or-Pay PPA arrangements. Consequently, without timely enhancement of domestic demand management, storage capacity, and cross-border trading infrastructure, Nepal risks facing growing volumes of underutilized surplus energy in the mid-term scenario turning a technical achievement into a financial burden.

1.3 Objectives

1.3.1 Main Objective

The primary objective of this study is to estimate the surplus hydropower potential available by Fiscal Year 2087/88 and to assess the prospects for cross-border electricity trade, particularly during the wet season.

1.3.2 Specific Objective

1. To collect and compile relevant data on power generation, transmission, and demand within the Integrated Nepal Power System (INPS),

2. To estimate the monthly surplus energy available during both wet and dry seasons,

3. To develop an Excel-based analytical model that projects surplus energy on an hourly basis, categorized by generation technology,

4. To analyze the existing and planned transmission infrastructure to identify potential constraints affecting cross-border electricity trade,

5. To evaluate the potential economic benefits of surplus energy utilization through export or assess the financial implications of generation curtailment

1.4 Scope

This study is systematically bounded to assess Nepal's surplus hydropower potential and cross-border trade prospects up to FY 2087/88. The study boundary is fixed at the medium-term horizon of FY 2087/88, with all analysis conducted upon the Integrated Nepal Power System (INPS). Off-grid systems and non-electric energy sectors are explicitly excluded to maintain a focused analysis on the national grid. The core execution of this dissertation is encompassed by the following five points scopes.

1. Generation Portfolio and Data Sources:
   The generation analysis is confined to projects with secured PPA with financial closure . It includes all hydropower categorized as RoR, PRoR, Storage, and Solar projects that have signed Power Purchase Agreements and have declared Required Commercial Operation Date (RCOD) before FY 2087/88. The forecast relies solely on official datasets and publications from the DoED, NEA, and WECS.

2. Deployment of Hourly Generation Profile and Scheduling:
   Methodologically, the research employs a quantitative approach, hourly resolution of generation profile developed in Microsoft Excel. This model integrates time-series generation profiles, built using historical Plant Capacity Factors

(PCF), Availability Factor (AF), and Multipliers Factor (MF), with projected hourly demand curves. A core component involves simulating and contrasting two operational dispatch strategies for flexible resources: a demand-following approach and a price optimized strategy aligned with DAM/RTM signals.

3. Transmission and Evacuation Analysis:
   The evaluation of power evacuation explicitly analyzes existing and committed cross-border transmission infrastructure. Capacity is assessed under the N-1 security criterion, with the system segmented into Zone 1 (Koshi, Madesh, and Bagmati) and Zone 2 (Gandaki, Lumbini, Karnali, and Sudurpaschim) to identify regional bottlenecks. The potential of proposed high voltage corridors to alleviate constraints is examined within this study.

4. Seasonal and Daily Surplus/Deficit Estimation:
   The primary output is a detailed quantification of energy surplus and deficit. The model calculates monthly and hourly balances, distinguishing between wet and dry seasons, and quantifies the volume of generation curtailment imposed by transmission limits. Export and import projections are derived from the interplay of this surplus, transmission capacity, and the selected dispatch strategy.

5. Economics of surplus energy utilization:
   A comparative financial assessment forms a key part of the evaluation. It estimates the annual export revenue under each dispatch case using prevailing market prices, calculating the incremental gain from price optimized scheduling. The economic cost associated with transmission induced curtailment is also explicitly quantified.

The study evaluates economic opportunities associated with CBET and highlight strategies to maximize national revenue through optimized utilization of surplus hydropower. The findings are expected to contribute significantly in policy formulation, investment prioritization, and long-term energy planning, ensuring that Nepals growing generation capacity is harnessed effectively and sustainably for regional energy cooperation.

1.5 Limitation of the Study

Due to the limited time and resource constraint to conduct this research, several assumptions were made which eventually limit the scope of this work. The study is based on projections and assumptions that may be affected by unforeseen political, economic, or climatic conditions. Real-time grid dynamics, pricing variability and behavioral aspect of power consumption are not considered. The study is primarily focused on quantifying excess hydropower potential for Nepal-India cross-border energy trade. This study will not cover potential trade with other countries like Bangladesh, China, and existing regional economic platform like BBIN, BIMSTEC, and SAARC framework.

1.6 Expected Outcome

This dissertation is expected to come up with following outcomes that is useful in optimal generation and CBTL planning to addressed risk of curtailment and transmission constraints by 2087/88.

At the end of this thesis work, excel based analytical model is deployed for analysis at different generation and demand scenario by 2087/88. This model will be used for the estimation of surplus hydropower energy available during dry and wet season in an hourly resolutions of the targeted year 2087/88. The output will also provide potential surplus trade at border points between Nepal and India. After execution of hourly dispatch scenarios in generation and demand, maximum capacity of transmission requirement will be identified. This value is pivotal for future recommendation in transmission line bottlenecks for infrastructure improvement. The study will also address Cross border potential and its opportunity in perspective of economics and prioritizing need for implementation of high voltage transmission lines.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of Power Generation in Nepal

Nepal possesses gross hydropower potential estimated as 72,544 MW. Similarly, WECS study has established a benchmark of 32,680 MW of technically and economically viable capacity [2]. This endowment provides the country with credible opportunities not only to meet its domestic electricity demand but also to export surplus hydropower energy to neighboring countries, primarily India and Bangladesh. Despite this potential, only about 5 percent of the total hydropower capacity has been harnessed to date, indicating a vast untapped resource base.

In recent years, Nepals power sector has experienced substantial growth in both generation and consumption [5, 9]. The Figure 2.1 illustrate annual energy available in the grid. According to NEA annual report, 2025 total energy available in grid was 15,641 GWh and domestic consumption in same year was 11,343 GWh which is reported to increased by 10.74 percent compared to the previous year. Electricity exports to India was recorded to 2,380 GWh which rose by 22.3% than previous year export. Nepal again recorded 699 GWh net sell of electricity to India corresponding to a CBET amounting NPR 4.57 billion, reflecting Nepals growing status as a net exporter of electricity [12].

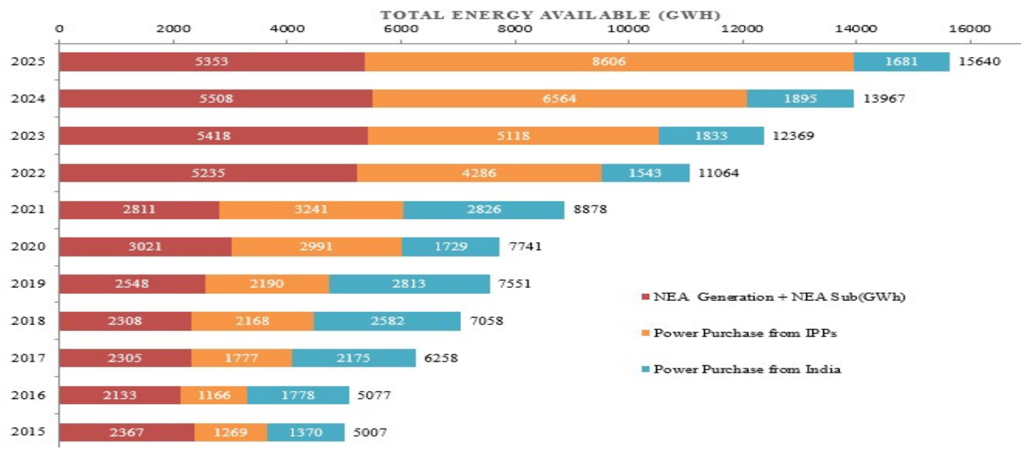

Figure 2.1: Annual Energy Available in Grid

By February 2025, out of 10,430 GWh of total energy available in the Integrated Nepal Power System (INPS), 8,665 GWh were utilized domestically, 1,765 GWh were exported, and 929 GWh were imported [12]. This represents a significant milestone shifting from historically dependent on imports to achieving net export capability. However, challenges persist during the dry season, when reduced hydropower generation leads to increased reliance on electricity imports from India to maintain supply reliability.

The Economic Survey (2024/25) [13] highlights further progress, with per capita electricity consumption rising to 422 kWh and access including both grid and off-grid supply expanding to 99 percent of the population. This transformation demonstrates Nepals substantial improvement in electricity infrastructure and accessibility within the past decade. This is marked by national generation capacity reaching 3,602 MW, marking a record addition of 463 MW within a single year [3]. Hydropower continues to dominate the generation mix, contributing approximately 3,336 MW, while the remaining capacity is shared among solar and thermal plants. The generation mix comprises about 55% from Independent Power Producers (IPPs), 34.2% from NEA and its subsidiaries, and 10.7% from imports, which together supported a total electricity availability of 15,641 GWh in 2025 [12].

NEA remains the key institutional player in the national power sector. The organizational structure is a vertically integrated utility, it owns and manages major generation assets totaling 661.57 MW [14] alongside a high voltage transmission network of 6,760 circuit kilometers and 14,123 MVA of substation capacity. In addition, NEA operates 224 circuit kilometers of cross-border transmission lines with a combined transfer capacity of 1,745 MW [12]. The authority continues to serve as the sole distributor of electricity within Nepal, playing a central role in maintaining system reliability and facilitating regional power trade.

2.2 Power Transmission and Cross-Border Interconnections

Nepals transmission network has expanded considerably over the past decade in line with the countrys growing power generation capacity and regional trade ambitions. As of 2025, the total length of the high-voltage transmission network stands at approximately 6,760 circuit kilometers, comprising 66kV, 132 kV, 220 kV, and 400 kV transmission lines distributed across the Integrated Nepal Power System (INPS). Table 2.1 below depicts transmission line length expansion of various voltage level in last ten years. The total substation transformation capacity has reached 14,123 MVA, marking a significant enhancement in the ability of the grid to accommodate new generation and ensure reliable power delivery across provinces [12].

Table 2.1: Circuit Kilometers by Voltage Level and Fiscal Year

S.N.	FY	Circuit Km				Total ckt km
		66 kV	132 kV	220 kV	400 kV	
1	2072/073	494	2,417			2,911
2	2073/074	494	2,596	75	78	3,243
3	2074/075	514	2,717	75	78	3,384
4	2075/076	514	3,143	255	78	3,990
5	2076/077	514	3,240	437	78	4,269
6	2077/078	514	3,541	741	78	4,874
7	2078/079	514	3,817	897	102	5,330
8	2079/080	514	3,979	1,101	148	5,742
9	2080/081	514	4,136	1,213	644	6,507
10	2081/82	514	4,193	1,266	787	6,760

The transmission infrastructure is primarily owned and operated by the Nepal Electricity Authority (NEA), while the Rastriya Prasaran Grid Company Limited (RPGCL), established to develop and manage strategic high capacity national and cross border transmission lines [15] are gradually taking over connecting major load centers and projects clustering hub. These institutions are jointly responsible for the planning, operation, and expansion of Nepals transmission backbone, ensuring system reliability and supporting future integration of renewable and large-scale hydropower plants.

Despite these advancements, transmission congestion and regional imbalances remain pressing issues. The Eastern and Central regions, particularly Koshi, Bagmati, and Gandaki Provinces host a dense concentration of hydropower projects [8], while the Western region has comparatively weaker transmission infrastructure. This spatial mismatch between generation and load centers contributes to line overloading and curtailment risks, especially during the wet season when hydropower production peaks.

In response to growing domestic and export requirements, Nepal has also prioritized the development of 400 kV transmission corridors and cross border interconnections with India. Several key projects are either completed or under construction, including:

1. Dhalkebar–Muzaffarpur 400 kV Line (Operational): The first high-capacity cross-border line, facilitating energy exchange between Nepal and India.

2. New Butwal–Gorakhpur 400 kV Line (Under construction): A major project expected to enhance export capacity from western region of Nepal before FY 2087/88.

3. Inaruwa–Purnea 400 kV Line (Proposed): Planned to strengthen eastern region export capability.

4. Lamki–Bareilly 400 kV Line (Proposed): Designed to improve cross-border power evacuation from far western Nepal.

At the present situation, existing cross border links collectively contribute to a transfer capacity of approximately 2,100 MW, distributed in various reason of Nepal at border points. However, this capacity remains insufficient to accommodate the projected surplus energy expected by FY 2087/88, particularly under N-1 contingency conditions, when line outages can significantly restrict export potential.

The ongoing and planned transmission projects are, therefore, critical to addressing both domestic evacuation constraints and cross-border trading limitations. Timely completion of these corridors, along with the expansion of high-voltage substations and grid interconnections, will be pivotal for enabling Nepal to efficiently utilize its growing hydropower capacity and strengthen its position as a regional power exporter.

2.3 Seasonal Generation Variability and the Need for Surplus Estimation

Due to the predominance of Run-of-River (RoR) hydropower plants, Nepals electricity generation is inherently seasonal. Peak generation occurs during the wet months (Jestha to Kartik) when river discharge is high, whereas the dry months experience significant reductions in generation output [16]. Basically, hydropower based RoR and PRoR source is more susceptible to climate change. This pronounced seasonal variation results in operational discrepancies and flexibility challenges within the Integrated Nepal Power System (INPS), which remains heavily reliant on RoR based generation.

According to Aryal et al. [17], the current generation mix lacks sufficient flexibility to manage this variability effectively. They emphasize the need for developing storage-type hydropower projects and adopting an energy banking mechanism to mitigate seasonal imbalances. Their study further suggests that increasing the share of storage hydropower to around 35 percent of the total generation capacity[18] could substantially reduce the risk of curtailment and loss of load, ensuring greater system reliability throughout the year.

The estimation of surplus energy plays a critical role in national infrastructure planning and resource optimization. Accurate quantification of surplus generation helps to minimize energy wastage, improve resource allocation, maintain a balanced demand-supply profile, and reduce national trade imbalances. The paper [19] suggested three pathways for surplus electricity utilization: expanding domestic electrical demand through sectoral switching, cross border electricity trading, and hydrogen capturing by electrolysis process. Several methodological approaches are commonly used for surplus estimation, depending on the scope and nature of the analysis:

- **Hydrological Flow Modeling:** Utilizes 20 to 30 years of river discharge data to analyze seasonal flow patterns and estimate energy availability under different hydrological conditions.

- **Simulation-Based System Modeling:** Models such as TIMES and LEAP are used for long-term energy planning and forecasting of surplus or deficit scenarios at a national scale [10].

- **Optimization and Network Models:** Tools such as MATPOWER, PSS/E, and OpenDSS are employed for load flow analysis and identification of transmission bottlenecks that affect the evacuation of surplus power.

Recent studies have attempted to quantify Nepals surplus energy using simulation-based approaches. Aryal and Dhakal [10] applied a TIMES-based optimization framework to project Nepals surplus energy potential by 2030. Their findings revealed that approximately 99,400 GWh of energy curtailment could be avoided through timely implementation of Cross-Border Electricity Trade (CBET), provided that the planned transmission lines are completed on schedule. Similarly, Thapa et al. [20] estimated that Nepal would have around 3,000 MW of surplus generation by 2030, while several other analysts have projected a range of 5,0008,000 GWh of exportable surplus energy within the same time frame.

Globally, MATLAB-based MATPOWER and other open-source power system modeling tools have been extensively used for network simulation and optimization studies. However, their application in the Nepalese context remains limited. Adopting such open-source platforms for simulating the Integrated Nepal Power System (INPS) offers a valuable opportunity to model hourly and monthly surplus generation under varying demand and hydrological conditions. This approach will support more informed decisions in generation scheduling, transmission planning, and cross-border trade optimization for future energy scenarios.

2.4 Load Forecast Methods and Understanding Demand Behavior

Load forecasting is a fundamental component of power system planning and operation, as it underpins decisions related to future generation expansion, transmission development, and identification of potential system bottlenecks. Accurate demand forecasts enable policymakers and operators to design timely interventions and allocate resources efficiently to maintain a reliable, secure, and economical balance between electricity supply and demand. A clear understanding of national electricity demand patterns is therefore essential for estimating future energy deficits or surpluses. Electricity consumption behavior is inherently influenced by end-user characteristics, natural phenomena, and broader socio-economic conditions, which collectively shape temporal and spatial demand variations within the power system [21].

Electricity demand behavior is closely linked to socio-economic drivers such as economic growth, industrial activity, demographic features, technological advancements, and policy interventions [1]. Changes in industrial production levels, the penetration of new electrical appliances, electrification of transport and heating, and shifts in consumer lifestyles can significantly alter load profiles [22]. In addition, government policies related to energy efficiency standards, tariff structures, and renewable energy integration further influence consumption patterns. These factors introduce complexity and uncertainty into demand forecasting, necessitating robust analytical frameworks capable of capturing both structural changes and dynamic consumer behavior[21].

A wide range of methodologies has been developed to forecast electricity demand, broadly classified into statistical methods, machine learning/artificial intelligence (ML/AI) techniques, and hybrid approaches. Statistical methods typically rely on historical data and established relationships between demand and explanatory variables, while ML/AI methods exploit data-driven learning to capture nonlinear and complex patterns. Hybrid models combine the strengths of multiple techniques and are generally reported to provide improved forecasting accuracy compared to single-method approaches[23, 24]. The selection of an appropriate forecasting method is closely tied to data availability, system characteristics, and the specific objectives of the study.

Demand forecasting is also differentiated by the time horizon of analysis. Long-term forecasts, typically extending beyond ten years, are critical for strategic planning of generation capacity, transmission expansion, and associated infrastructure investments. Medium-term forecasts, spanning one to ten years, support fuel procurement planning, maintenance scheduling, financial resource allocation, and tariff formulation. Short-term forecasts, ranging from hourly to annual horizons, are essential for system operation, including unit commitment, spinning reserve management, and identification of operational constraints. In practice, forecasting exercises may adopt qualitative, quantitative, or hybrid approaches. Qualitative methods rely on expert judgment and scenario analysis, particularly when historical data are limited or unreliable, whereas quantitative methods employ mathematical and statistical models based on historical trends. Hybrid approaches integrate both perspectives to enhance forecast robustness and adaptability to evolving demand behavior[21].

2.5 Cross-Border Electricity Trade (CBET) and Regional Context

Nepals power sector has undergone a structural transformation in recent years, shifting from chronic electricity deficits to a position of seasonal surplus driven predominantly by hydropower development. This transition has elevated renewable electricity from a domestic supply resource to a strategic asset for regional energy security. A fundamental driver of cross-border electricity trade (CBET) is the strong complementarity between Nepals generation profile and the demand patterns of neighboring countries. Nepal experiences peak hydropower generation during the monsoon months (JuneSeptember), which coincides with periods of high summer electricity demand in North India and Bangladesh. This seasonal synergy enhances the economic and operational attractiveness of Nepali electricity exports and positions Nepal favorably within the regional power market[25].

India constitutes the principal destination for Nepals electricity exports and plays a central role in the regional CBET framework. In alignment with its long-term renewable energy and zero carbon goal by 2070 [26] , India has expressed its commitment to import up to 10 GW of electricity from Nepal by 2035. Correspondingly, the Government of Nepal has articulated an Energy Development Road map that prioritizes hydropower based export growth and reinforces bilateral and tripartite energy cooperation with neighboring countries. These policy alignments underscore the strategic importance of CBET in Nepals national energy planning and its integration with regional power systems [11].

The realization of expanded cross border trade is closely linked to the availability and adequacy of transmission infrastructure. At present, Nepal exports approximately 1,200 MW of electricity to India [12], primarily through the DhalkebarMuzaffarpur 400 kV double-circuit transmission line, which serves as the backbone of cross-border power exchange. This interconnection is complemented by several lower-voltage links at 132 kV and 33 kV levels. However, scaling exports to meet projected trade volumes necessitates substantial augmentation of cross-border transmission capacity. Key projects under development include the Butwal-Gorakhpur 400 kV transmission line, which will create a high-capacity evacuation corridor for central and western Nepal, and the planned LamkiBareilly 400 kV line, and Inaruwa-Purnea 400 kV line aimed at integrating hydropower resources from the far-western Karnali basin into regional markets while alleviating internal congestion[9, 15, 27].

In parallel with physical infrastructure expansion, the institutional and market mechanisms governing CBET have evolved significantly. NEA now trades electricity through Indias DAM and RTM through the Indian Energy Exchange platform, enabling price bidding and revenue optimization for surplus power. Furthermore, Nepal has taken initial steps toward multilateral electricity trade through a landmark tripartite agreement signed in October 2024 among NEA, NTPC Vidyut Vyapar Nigam Ltd. (NVVN) of India, and the Bangladesh Power Development Board. This arrangement allows the export of Nepal's hydropower to Bangladesh using the Indian transmission network as a wheeling corridor, setting a precedent for broader regional cooperation. These developments are reinforced by regional policy initiatives such as SAARC energy framework and the BBIN framework, which aim to enhance cross-border connectivity and institutional collaboration in the power sector [10]. However, there is also a need to establish a harmonized power procurement and pricing mechanism among the countries in a framework that would facilitate greater cross-border electricity trade, investment, and regional energy security in South Asia [28].

CHAPTER THREE: METHODOLOGY

The methodological framework adopted in this study follows a structured, step-wise approach designed to estimate national and regional surplus hydropower potential and to evaluate the prospects for cross-border electricity trade by FY 2087/88. The overall workflow, illustrated in Figure 3.1, consists of five sequential stages, each building upon the preceding step to ensure analytical coherence and data consistency.

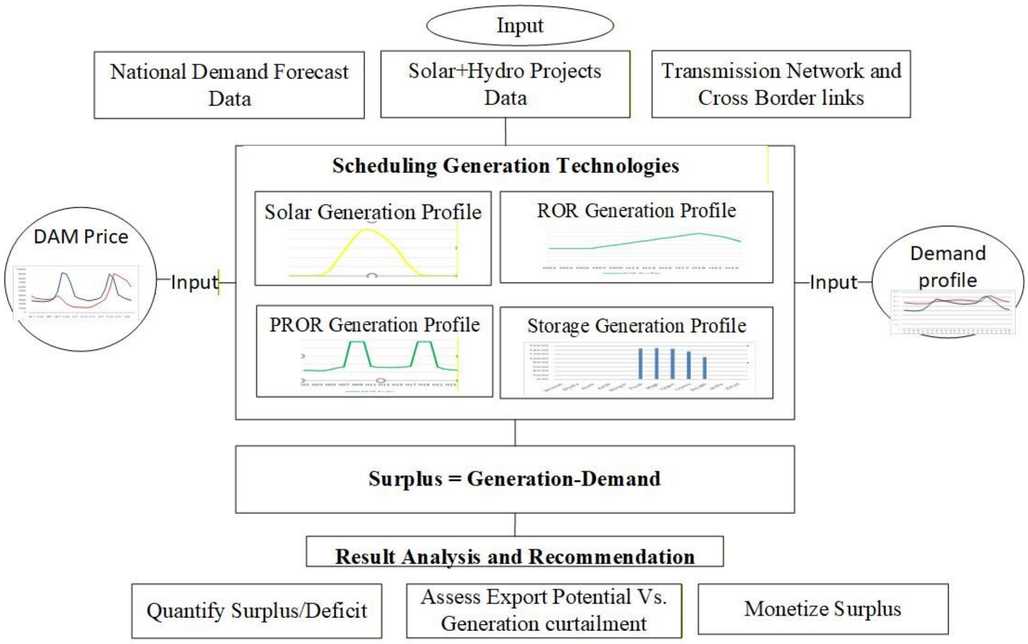

Figure 3.1: Methodological framework for surplus estimation and CBET Analysis

Step 1: Data Collection and Processing: The study begins with the compilation of reliable datasets from multiple institutional sources, including the Department of Electricity Development (DoED), Nepal Electricity Authority (NEA), and Water and Energy Commission Secretariat (WECS). The datasets encompass generation project attributes (capacity, technology type, RCOD, and capacity factors), national demand forecasts, and the existing and planned transmission network, including cross-border interconnections. Data were cleaned, standardized, and integrated to form a unified database suitable for subsequent modeling and simulation.

Step 2: Hourly Projection of Generation Profiles: Generation profiles for the four major technologies RoR, Peaking RoR, Storage, and Solar were developed at an hourly resolution. The energy outputs were estimated using plant specific capacity factors and seasonal availability/multipliers derived from operational data and solar resource data. These hourly generation profiles reflect realistic seasonal and temporal variability, forming the core input for the surplus estimation model.

Step 3: Scheduling of Flexible Generators: The study employs two distinct scheduling strategies to analyze operational flexibility and economic performance:

- Case 1: Load Profile-Based Scheduling, where PRoR and Storage plants are dispatched to follow national load peaks time slots and maintain domestic reliability.

- Case 2: Price-Based Scheduling, where flexible generators are optimized according to Day-Ahead Market price signals to maximize export revenue.

These scenarios enable comparative evaluation between prioritizing domestic peak and market-oriented operations.

Step 4: Estimation of Surplus and Deficit: At this stage, the net energy balance is computed as the difference between generation and demand on an hourly, monthly, and annual basis. The surplus estimation is conducted at both national and zonal levels (East and West INPS zones), accounting for transmission line capacities and N1 contingency criteria. This step identifies seasonal and regional energy surpluses, potential deficits, and the extent of generation curtailment due to transmission constraints.

Step 5: Result Analysis and Recommendation: The final step focuses on the interpretation of results and policy-oriented analysis. It quantifies the total surplus energy available for export, evaluates the utilization of cross-border transmission infrastructure, and assesses the economic benefits of each scheduling strategy. The analysis includes estimation of curtailed energy, monetary value of surplus trade, and revenue gain from flexible generation scheduling. Recommendations are then drawn to guide future planning for generation optimization, transmission reinforcement, and cross-border electricity trade enhancement.

The overall methodological approach for this study is illustrated in Figure 3.1, which outlines the sequential process of data collection, generation scheduling, surplus estimation, and result evaluation. The framework initially considers four generation technologies RoR, Peaking RoR, Storage, and Solar scheduled according to either load based or market price based dispatch scenarios. However, to further enhance system flexibility and maximizing revenue, the methodology was later extended to include Pumped Storage Hydropower (PSH) as an additional component of the generation mix. The enhanced version of the framework incorporating PSH is presented in Figure 3.3, described in detail in Section 3.4.

3.1 Data Collection and Validation

Comprehensive data were compiled from official and validated sources. The DoED database[3] provided hydro power licensing and commissioning records for 517 projects, while NEA Annual Reports (2015–2024) offered historical operational data on generation and demand. Hourly Availability Factors (AFs) were derived from Load Dispatch Center (LDC) log sheets (2018–2019), which serve as the basis for hourly demand and generation scheduling. Transmission system and cross-border line data were sourced from NEA [9, 12], Rastriya Prasaran Grid Company Limited (RPGCL) [27, 15], and long-term demand projections were obtained from WECS, 2017 [1, 2, 6]. All data were cross verified for consistency and completeness.

Table 3.1: Summary of Data Sources and Applications

Data Source	**Data Set Types**	**Records**	**Coverage Period**	**Primary Application**
DOED Database Project Licensing	517 nos	2025	FY2024/25	Pipeline Analysis
NEA Operations Report	Generation Data	19 nos	2015–2024	Performance Assessment (PCF estimation)
LDC, NEA	INPS Operational Data	Daily Logsheet	2018–2019	Technical Analysis, hourly MF, and AF calculation
NEA Transmission Directorate	Transmission Grid, expansion and Connectivity	6,760 ckt km	2020–2024	Infrastructure Planning, assessment of CB trade potential

3.2 Demand Forecasting

Demand forecasting is a critical component of power system planning and serves as the foundation for evaluating Nepals future generation adequacy, investment prioritization, and surplus energy estimation. Accurate projections of national electricity demand allow planners to identify required generation capacity, optimize transmission infrastructure expansion, and ensure system reliability during peak load conditions.

In Nepal, several government agencies and institutions have developed own demand projections using different modeling frameworks and assumptions. WECS, NEA, and IBN have engaged in long-term electricity demand forecasting. Among these, WECS commonly employs the Model for Analysis of Energy Demand (MAED), which links socio-economic and demographic variables with sectoral energy consumption to generate comprehensive demand scenarios. In contrast, NEAs approach is more operational, relying on historical demand trends and electrification growth, while IBN adapts the MAED framework by incorporating latent demand and project pipeline impacts to assess future energy needs more holistically.

Each institutions forecast differs slightly in methodology, assumptions, and focus area. Table 3.2 summarizes the comparative characteristics of these three approaches.

Table 3.2: Electricity Demand Forecast Methodologies Comparison [1, 6, 22]

Org.	**Forecast Methodology**	**Base Year**	**GDP Growth**	**GWh in 2030**	**MW in 2030**
WECS	MAED model with sectoral demand analysis	2014/15	BAU: 4.5% Ref: 7.2% High: 9.2%	20,073 24,956 29,864	8,937 11,111 13,296
NEA	Historical sectoral demand trend electrification growth	2013/14	Phase I: 4.59 Phase II: 6.07%	19,103 24,551	4,614 5,930
IBN	MAED with project pipeline and latent demand	2014	Base: 5% Medium: 7% High: 10%	33,437 38,299 48,706	6,358 7,286 9,266

The comparison reveals that WECS provides the most comprehensive, scenario-based model by integrating macroeconomic indicators with sectoral energy demand. It develops three growth scenario Business-as-Usual (BAU), Reference, and High Growth corresponding to GDP growth rates of 4.5%, 7.2%, and 9.2%, respectively [1]. The Reference Scenario, assuming moderate economic growth and realistic electrification expansion, is considered most appropriate for medium-term energy planning.

The NEA forecast [6], on the other hand, adopts a conservative operational perspective, emphasizing system planning, transmission constraints, and historical consumption patterns. While it produces lower estimates compared to WECS, it provides a more pragmatic view aligned with grid operation and implementation feasibility.

In contrast, the IBN forecast[22] expands upon the WECS MAED model by integrating the effects of upcoming hydropower projects, industrial corridor development, and latent energy demandthat is, the demand currently unserved due to supply limitations. Its projections are higher, reflecting the anticipated increase in electricity use from large-scale infrastructure and cross-border trade readiness initiatives.

Among these, the WECS Reference Scenario (7.2% GDP growth) is adopted in this study as the baseline demand projection for FY 2087/88, considering its methodological comprehensiveness and alignment with national energy planning frameworks. This forecast forms the foundation for subsequent generation demand simulations and surplus estimation presented in later sections of this thesis.

WECS Demand Forecast

The Water and Energy Commission Secretariat (WECS) has employed the Model for Analysis of Energy Demand (MAED) to forecast Nepals electricity demand over a twenty-five-year period from 2015 to 2040 [1]. The MAED model is a bottom-up simulation tool that correlates population growth, economic expansion, industrial development, transportation electrification, and technological advancement with projected electricity consumption across different sectors of the economy [1, 22].

The modeling process begins with a comprehensive database of current energy consumption patterns, segregated into residential, commercial, industrial, agricultural, and transport sectors. This baseline data is integrated with key macroeconomic indicators such as GDP growth rate, urbanization trends, and national policy targets for electrification and economic transformation. Through this integrated framework, the model establishes relationships between socioeconomic parameters and sectoral electricity requirements.

To capture future uncertainties, WECS developed three growth scenarios:

- **Business-as-Usual (BAU)** assuming moderate economic growth of approximately 4.5% GDP per annum.

- **Reference Scenario** representing the governments planned development trajectory with an average 7.2% GDP growth rate.

- **High Growth Scenario** reflecting an accelerated development pathway with 9.2% GDP growth rate.

Under each scenario, MAED calculates the final electricity demand for individual sectors and aggregates them to determine the national electricity requirement for each projection year. The forecasts are then adjusted to include transmission and distribution losses, system reserves, and outage margins to estimate the total installed capacity requirement necessary to ensure reliable supply.

The resulting demand projections serve as a critical input for long-term generation expansion planning, surplus estimation, and cross-border energy trade analysis providing an evidence based foundation for policy and investment decisions in Nepals power sector.

Table 3.3: Projected Energy Demand (in MWh) under Different Scenarios

Year	**BAU (4.5%)**	**Reference 7.2%**	**High 9.2%**	**Policy Intervention 7.2%&9.2%**	
2015	3866	3866	3866	3866	3866
2020	7601	8111	8523	14871	15304
2025	12998	14864	16546	22432	24265
2030	20074	24957	29864	35335	41265
2035	29745	40710	52983	51772	65658
2040	43017	66097	94851	81959	115294

Table 3.3 represents energy forecast by WECS under various scenarios of GDP growth. It was observed that electricity demand for FY 2087/88 was forecast under the WECS Reference Scenario assuming a 7.2 percent annual GDP growth rate that is estimated to 24,957 GWh [1]. Monthly demand distribution was derived using seasonal load multipliers, while hourly load curves were constructed using normalized factors derived from operational level data. Figure 3.2 is a fraction of annual demand occuring in every time slices. This demand multiplier is applied to construct hourly load profile. This approach ensures realistic time-based representation of load variations across all months.

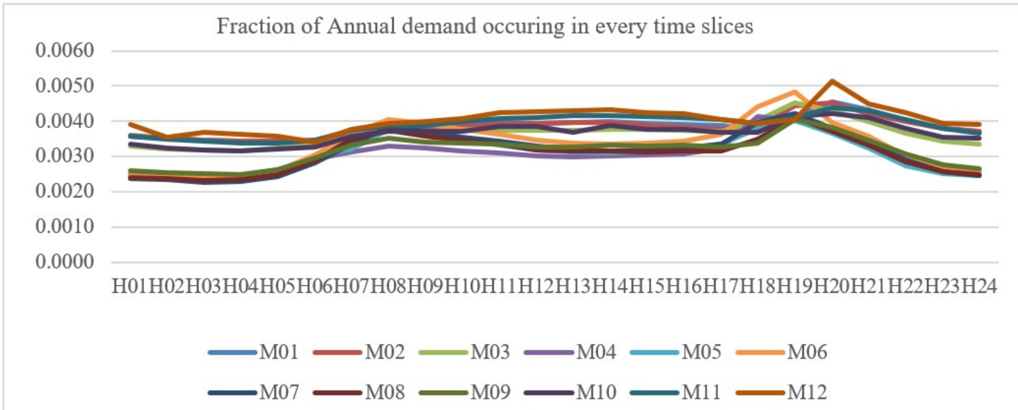

Figure 3.2: Demand multipliers for every fraction of time slices

The electricity demand forecast prepared by WECS serves as a fundamental input to this studys analytical framework. The Reference Scenario (7.2% GDP growth) is adopted as the baseline for projecting demand up to FY 2087/88, aligning with national planning assumptions. This projected demand is integrated into the thesis model to estimate hourly and seasonal energy balances, enabling accurate assessment of surplus generation potential and corresponding transmission and cross-border trade requirements.

3.3 Generation Forecast

This section outlines the methodology adopted to estimate the potential hydropower and solar generation in Nepal by Fiscal Year 2087 B.S. The forecasting process integrates multiple verified datasets and official publications, including project information from the Department of Electricity Development (DoED) database, the Royalty Management System (RMS), and project progress reports from the Project Inspection Division of DoED. In addition, the Power Purchase Agreement (PPA) and Required Commercial Operation Date (RCOD) status of projects were verified through Nepal Electricity Authority (NEA) publications, while planning assumptions were derived from the Energy Development Roadmap (2024) of the Ministry of Energy, Water Resources, and Irrigation (MOEWRI) [11] and the Water and Energy Commission Secretariat (WECS) [29].

A total of 202 operational hydropower and solar projects and 315 licensed or under-construction projects were reviewed for the analysis. The generation forecast was structured by categorizing these projects into three distinct groups based on their operational, construction progress, and financial closure for construction:

- **Group I Operational Projects:** All projects that were already commissioned and operational as of FY 2024/25.
- **Group II Projects Under Construction:** Projects with secured PPAs and RCODs before FY 2087/88, representing facilities expected to be commissioned within the study horizon.
- **Group III Pipeline Projects:** Candidate hydropower and solar projects that have obtained PPAs but are in preliminary stages of financial closure and construction. These projects were included based on available information on physical progress and expected commissioning schedules.

Finally, the annual energy generation (in GWh) is estimated by adding monthly generation available directly form plant information or indicated in the Project report submitted to DoED. Likewise, project with missing monthly energy information is calculated using the fundamental relationship between installed capacity (P_{inst}), operational hours (T_h) in a year, and the capacity factor (CF):

$$E_{\text{annual}}\ (\text{GWh}) = \frac{P_{\text{inst}}\ (\text{MW}) \times T\ (\text{h}) \times \text{CF}}{1000} \tag{3.1}$$

The capacity factors and seasonal energy distribution percentages were assigned based on plant type and validated from Detailed Project Reports (DPR), PPA documents, and operational data of existing plants. Reference values were also compared with assumptions from Gyanwali et al. [30], who proposed CFs of 0.64 and 0.40 for RoR and Storage schemes, respectively. The final default assumptions applied in this study are summarized in Table 3.4 below:

Table 3.4: Default assumption for plant Capacity Factor

Plant Scheme	Capacity Factor (CF)	Dry Season (%)	Wet Season (%)	Reference / Remarks
RoR (4/8, 6/6 months PPA)	0.55	16.33 30.85	83.67 69.15	Derived from average NEA and IPP data
PROR (6/6 months PPA)	0.52	30.85	69.15	Derived from average NEA and IPP data
Storage	0.457	35.00	65.00	from the operational report published

Given the strong seasonality of hydropower output, the annual generation was divided into dry and wet season contributions using the following relationships:

$$E_{\text{dry}}\ (\text{GWh}) = E_{\text{annual}}\ (\text{GWh}) \times \%\ \text{Dry Energy share} \tag{3.2}$$

$$E_{\text{Wet}}\ (\text{GWh}) = E_{\text{annual}}\ (\text{GWh}) \times \%\ \text{Wet Energy share} \tag{3.3}$$

where,

- Dry Season: Mangsir 16 Jestha 15
- Wet Season: Jestha 16 Mangsir 15

Typically, RoR and PROR projects generate approximately 70% of their annual energy during the wet season and 30% during the dry season, while storage projects provide a more balanced generation profile of about 65% wet and 35% dry.

The future trajectory of Nepals electricity generation is therefore determined by the combined contribution of projects that are operational, under construction, or financially secured within the planning horizon. These datasets form the foundation for forecasting total available generation by FY 2087/88, which is subsequently analyzed in this study to assess seasonal surplus potential, transmission adequacy, and cross-border trade opportunities.

3.4 Integration of Pumped Storage Hydropower (PSH) in the Surplus Estimation Model

Building upon the base methodological structure shown earlier in Figure 3.1, this section introduces an improved analytical framework that integrates Pumped Storage Hydropower (PSH) into the surplus estimation model. The updated framework, shown in Figure 3.3, introduces an additional layer of operation logic that allows the system to absorb surplus solar and RoR generation during low-price hours and release stored energy during high-price periods [31]. This enhancement enables a more accurate and economically optimized estimation of surplus generation and cross-border trade potential by 2087/88.

The proposed methodology in Figure 3.3 builds upon the existing hourly supply demand framework developed in previous sections and introduces a PSH operation layer that interacts with Solar, RoR, PRoR, and Storage plants. The methodological process consists of five sequential steps, as illustrated in the following subsections.

Step 1: Definition and Model Inputs

The first step involves formulating the operational strategies and identifying key model parameters and constraints. The hourly surplus energy available in the system is defined as:

$$\text{Surplus}[m,h] = (\text{Solar}[m,h] + \text{RoR}[m,h] + \text{PRoR}[m,h] + \text{Storage}[m,h]) - \text{Demand}[m,h]$$

Here,

m represents the month,
h represents the hour of the day,
Generation and Demand values are expressed in MW.

The PSH plant has a total installed generation capacity of 928.5 MW [3], which defines the maximum permissible hourly power for both pumping and generation operations. In this model, the schedules of PRoR and conventional storage plants are considered fixed, as they have already been optimized for market based dispatch (Case 2 scenario) for maximizing revenue from CBET.

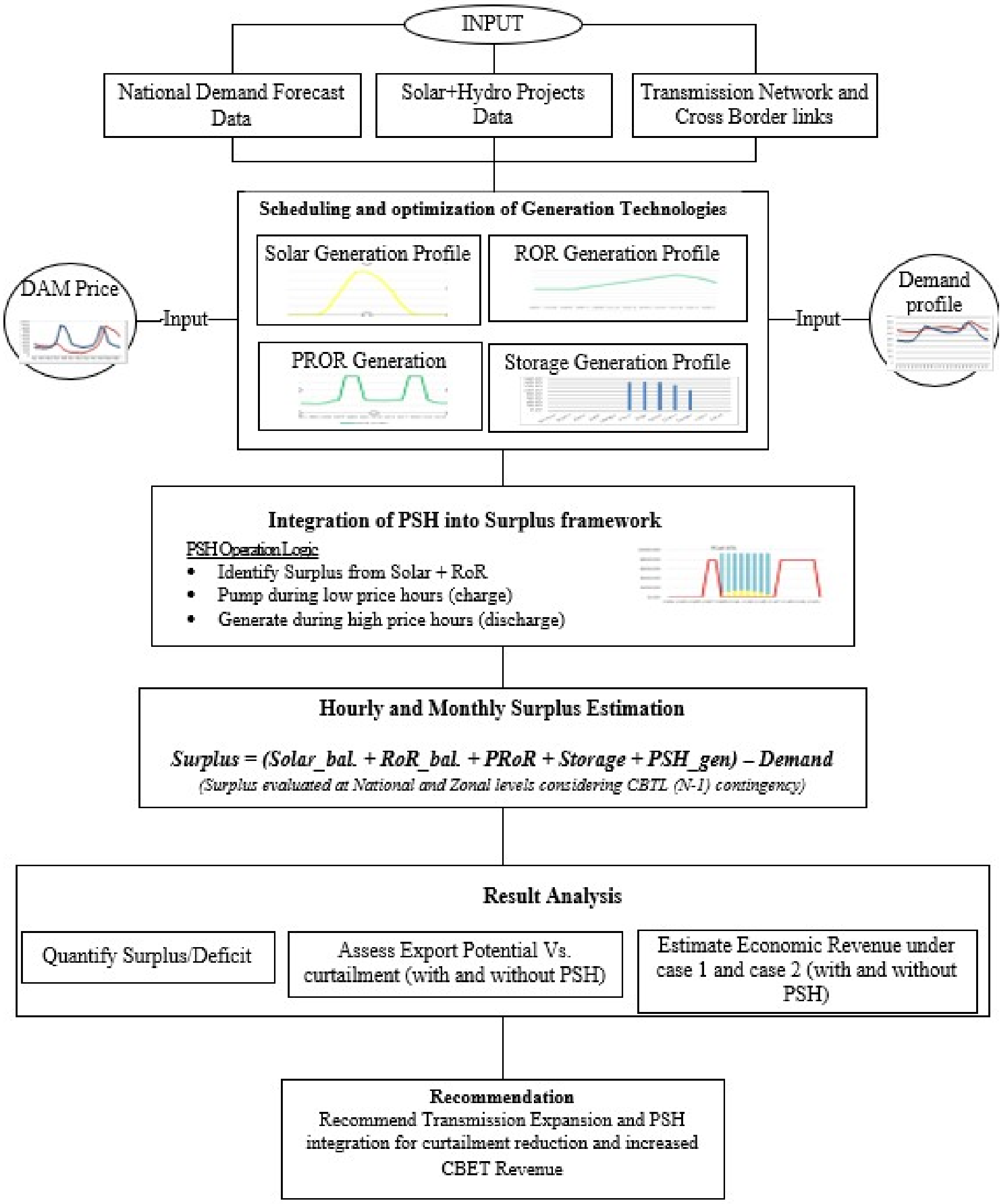

Figure 3.3: Methodological framework with Integrated PSH for surplus estimation and CBET Analysis

The main operational assumptions are as follows:

1. During wet months (Jestha 16–Mangsir 15), excess Solar and RoR generation after meeting domestic demand is utilized for PSH pumping.

2. During dry months (Mangsir 16–Jestha 15), PSH operates in a mixed strategy pumping energy during low-price hours (typically morning and midday) and

generating during evening peaks or high-price intervals to capture market price differentials.

3. PSH operation must maintain energy balance such that no simultaneous pumping and generation occur within the same hour.

Step 2: Defining Hourly Pumping Logic

Hourly pumping energy is computed based on available excess generation after fulfilling domestic demand. The raw hourly energy allocated for pumping $E_{\text{pump,raw}}[m, h]$ is determined by comparing the hourly surplus with the PSH plants maximum capacity, as expressed in Equation

$$E_{\text{pump,raw}}[m, h] = \begin{cases} 928.5, & \text{if Excess}[m, h] \geq 928.5, \\ \text{Excess}[m, h], & \text{if } 0 < \text{Excess}[m, h] < 928.5, \\ 0, & \text{if Excess}[m, h] \leq 0 \end{cases} \tag{3.4}$$

Where, $\text{Excess}[m, h] = Solar[m, h] + RoR[m, h] - Demand[m, h]$

This ensures that pumping occurs only when surplus renewable generation is available, with a maximum limit of 928.5 MW. When no excess energy exists, the PSH remains idle in pumping mode.

Step 3: Market-Based Operating Logic

To simulate market-driven operation, a price-based decision key $Pump_{\text{key}}[m, h]$ is developed for each hour. This binary key presented in Appendix **D Table A.1** determines whether the PSH is in pumping mode (1) or generation mode (0), based on the relative position of the Day-Ahead Market (DAM) price to the average hourly price. The operational logic is as follows:

- When the DAM price is below the average hourly price, the PSH operates in pumping mode; $Pump_{\text{key}}[m, h] = 1$
- When the DAM price is above the average hourly price, the PSH operates in generation mode; $Pump_{\text{key}}[m, h] = 0$

Please refer to **Appendix D Table A.1** for PSH operational strategy.

Once the operating key is defined, the actual hourly energy used for pumping

$E_{\text{pump}}[m,h]$ is derived as:

$$E_{\text{pump}}[m,h] = \begin{cases} E_{\text{pump,raw}}[m,h], & \text{if } Pump_{\text{key}}[m,h] = 1 \\ 0, & \text{if } Pump_{\text{key}}[m,h] = 0 \end{cases} \tag{3.5}$$

The stored energy available for subsequent generation is calculated by applying a round-trip efficiency of 85% [32], which accounts for mechanical, hydraulic, and electrical losses in the PSH system:

$$E_{\text{pump,Gen}}[m,h] = 0.85 \times E_{\text{pump}}[m,h] \tag{3.6}$$

This stored energy is later utilized for generation $E_{\text{pump}}[m,h]$ during the hours identified as high price intervals ie. $Pump[m,h] = 0$

Step 4: Energy Balancing and Surplus Estimation

Equations 3.7 and 3.8 represents fraction Solar and RoR utilized by the PSH to operate pump .

$$E_{\text{pump,solar}}[m,h] = E_{\text{pump}}[m,h] \frac{Solar[m,h]}{Solar[m,h] + RoR[m,h]} \tag{3.7}$$

$$E_{\text{pump,RoR}}[m,h] = E_{\text{pump}}[m,h] \frac{RoR[m,h]}{Solar[m,h] + RoR[m,h]} \tag{3.8}$$

After pumping operations, the amount of Solar and RoR energy used for pumping must be deducted from their respective generation profiles to maintain energy conservation. The adjusted hourly generation for Solar and RoR is therefore expressed as given by Equations 3.9 and 3.10:

$$E_{\text{Solar}}[m,h] = Solar[m,h] - E_{\text{pump,solar}}[m,h] \tag{3.9}$$

$$E_{\text{RoR}}[m,h] = RoR[m,h] - E_{\text{pump,RoR}}[m,h] \tag{3.10}$$

The final surplus for each hour is then estimated as:

$$\begin{aligned} Surplus_{\text{PSH}}[m,h] = {} & E_{\text{Solar}}[m,h] + E_{\text{RoR}}[m,h] + E_{\text{PRoR}}[m,h] \\ & + E_{\text{Storage}}[m,h] + E_{\text{pump,Gen}}[m,h] - E_{\text{Demand}}[m,h] \end{aligned} \tag{3.11}$$

Step 5: Estimation of Revenue and Performance Evaluation

The final stage involves quantifying the economic implications of PSH operation. The hourly exportable energy from the surplus series is mapped to corresponding

DAM price profiles to estimate revenue under market-based scheduling. Revenue R[m,h] is computed as:

$$R[m,h] = Surplus_{\mathrm{PSH}}[m,h] \times P_{\mathrm{DAM}}[m,h] \tag{3.12}$$

Where, $P_{\mathrm{DAM}}[m,h]$ is hourly market clearing price of electricity in the Indian Energy Exchange (IEX).
Therefore, aggregated annual revenue is obtained as:

$$R_{\mathrm{annual}} = \sum_{m=1}^{12} \sum_{h=1}^{24} R[m,h] \tag{3.13}$$

The inclusion of PSH in the model provides additional flexibility in aligning Nepal's generation with regional price signals. During wet season months (Jestha to Mangsir), PSH absorbs excess Solar and RoR energy that would otherwise be curtailed due to transmission limitations. The stored energy is then exported during high price hours, enhancing revenue from cross border trade. Similarly, in dry season months, PSH helps balance limited RoR generation by utilizing low cost imports for pumping and delivering higher value exports during evening peaks.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents the integrated quantitative results of the generation forecast, hourly energy balance simulation, regional (zone-wise) surplus assessment, transmission adequacy evaluation, and financial analysis of Nepals surplus hydropower potential by FY 2087/88. The analysis synthesizes all data sources that includes DOED project records, NEA operational datasets, LDC hourly logs, WECS demand forecast, and cross-border transmission capacities inputted into an Excel-based simulation environment that evaluates energy surplus at hourly, monthly, seasonal, and regional scales.

4.1 Installed Capacity and Energy Outlooks

The data presented in the Table 4.1 summarizes Nepal's projected generation landscape by FY 2087/88, categorized according to project development status of hydropower and solar projects. A summary table is presented in **Appendix A A.1** and list of hydropower with their physical progresses and expected Required Commercial Operation Date (RCOD) is tabulated in **Appendix F A.1 and A.2** . A total of 402 projects are considered, representing a combined installed capacity of 9,289 MW and an estimated annual generation of 42,501 GWh. Among these, hydropower projects under construction constitute the largest share of 4,726 MW of capacity and 24,787 GWh of annual generation indicating that ongoing construction activities will be the main driver of future capacity expansion. Operational hydropower plants contribute 3,393 MW and 15,578 GWh, while projects in the pre-construction phase add another 526 MW with 2,893 GWh of expected output. Solar projects, though smaller in scale, collectively amount to about 1,170 MW and generate approximately 2,136 GWh annually, signifying gradual diversification of the national energy mix. Figure 4.1 represents percentage contribution in the grid according to generation schemes. RoR share reflects largest fraction while Storage hydropower have representative figure which need to boost for maintaining seasonal balances. The seasonal distribution of generation 12,706 GWh (30%) in the dry months and 29,795 GWh (70%) in the wet months reinforces the hydropower dominated system with strong dependence on monsoon inflows and highlights the continuing need for storage capacity and cross border trade mechanisms to effectively utilize surplus energy during the wet season.

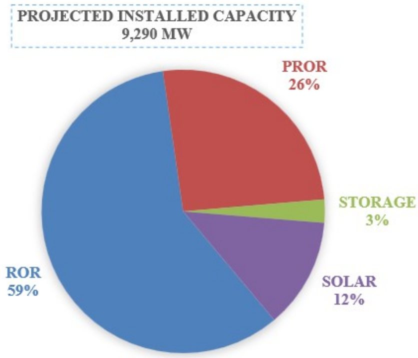

Figure 4.1: Projected capacity by FY 2087/88

Table 4.1: Project summary by type and status

Projects	Nos	Capacity MW	Annual Energy	Dry	Wet
HP Operation	177	3393	15578	4658	10921
HP Construction	127	4726	24787	7033	17755
Solar Operation	25	142	259	123	136
Solar Construction	73	1028	1877	894	983
Total	402	9289	42501	12707	29795

Table 4.2 illustrates the projected capacity addition trajectory of Nepals power system from the base year FY 2081/82 through FY 2087/88, highlighting a steady and accelerated growth pattern in generation capacity. Starting with an existing capacity of 3,535 MW in FY 2081/82, the system is expected to expand to 9,289 MW by FY 2087/88 with overall increase of approximately 5,660 MW within five years, representing more than a two and half folds growth in installed capacity.

Table 4.2: Capacity Addition and Cumulative Capacity by Fiscal Year

FY	No.	Capacity addition (MW)	Cumulative Capacity (MW)
FY_2081/82	202	3535	3535
FY_2082/83	11	297	3832
FY_2083/84	24	439	4271
FY_2084/85	22	688	4958
FY_2085/86	35	1404	6362
FY_2086/87	61	1399	7762
FY_2087/88	47	1528	9289

4.2 Demand Forecast and Seasonal Load Profile

The national electricity demand for FY 2087/88 was estimated using the WECS Reference Scenario, which assumes an average economic growth rate of 7.2 percent per year. Under this scenario, the projected annual energy requirement reaches 24,957 GWh, reflecting the combined effects of population growth, industrial expansion, increased electrification of transport, and rising residential appliance usage [1].

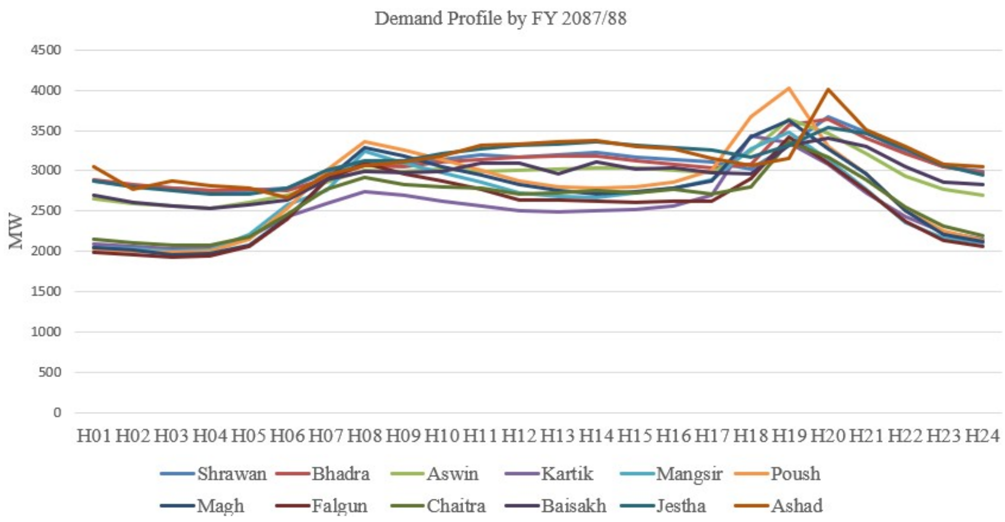

Figure 4.2: Projected Demand by FY 2087/88

To capture realistic temporal variations, the annual demand was disaggregated into monthly and hourly profiles using normalized demand multipliers derived from NEA Load Dispatch Center (LDC) operational logs for 2018-2019. These multipliers reveal clear seasonal and diurnal load characteristics: electricity consumption peaks during the winter months due to heating and lighting requirements, while relatively lower demand is observed during the monsoon season. Hourly load curves show a persistent evening peak between 18:00-21:00, a moderate morning rise, and a midday flattening influenced by commercial and industrial activities. This seasonal and hourly load behavior plays a critical role in shaping the energy balance of the Integrated Nepal Power System (INPS), particularly when contrasted with the hydropower-dominated supply profile, which inherently fluctuates with river discharge and solar availability. As a result, understanding the temporal demand dynamics is essential for accurately assessing surplus availability, identifying deficit periods, and determining the appropriate scheduling strategy for hydropower dispatch and cross-border power trade.

4.3 Hourly Generation Model and Technology wise Profiles

The hourly generation model used in this study simulates the year-round performance of each generation technology by applying availability factors (AFs) on an hourly basis across the 8,760 hours of the year. These AFs were derived from historical operational data, technical literature, and region specific solar irradiation and hydrological patterns. Hourly-AFs designed for RoR, Solar and multiplier derived for Demand is presented in **Appendix B A.1, A.2, and A.3**. This approach allows the model to closely replicate realistic operational behavior of Nepals hydropower-dominated system, particularly its strong dependence on seasonal river flow and daily solar exposure patterns. The resulting hourly profiles form the foundation for estimating surplus and deficit periods, evaluating cross-border evacuation limitations, and comparing the two dispatch strategies for Peaking Run-of-River (PRoR) and Storage hydropower plants. The following subsections detail the hourly performance characteristics of each generation technology.

4.3.1 Solar generation Profile

Solar Photovoltaic (PV) generation were modeled using hourly AF based on solar irradiance patterns typical of the Nepal's context. Figure 4.3 shows solar profiles with quantum of generation estimated by FY 2087/88. These profiles exhibit a clear diurnal pattern, with negligible generation during nighttime and rising output beginning around 6:00 AM as solar radiation increases. Peak generation occurs between 10:00 and 14:00 hours, corresponding to the highest solar elevation, after which generation declines steadily toward evening. Seasonal variability is also evident that depicts solar output is higher during the dry winter months due to clearer skies, whereas monsoon cloud cover leads to reduced output despite longer day lengths. While solar represents a growing share of total installed capacity, its contribution to peak system demand is limited because its production coincides mostly with midday hours rather than evening peaks. Consequently, solar power plays a crucial role in increasing daytime surplus, especially during the wet season, thereby influencing export scheduling and potential curtailment.

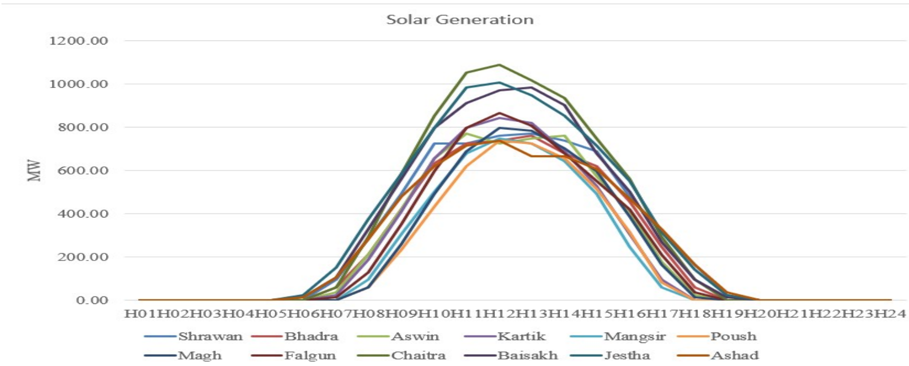

Figure 4.3: Solar Generation Capture by FY 2087/88

4.3.2 Run-of-River Generation

Run-of-River (RoR) hydropower plants were modeled using hourly AFs derived from historical river flow data and operational logs from the Load Dispatch Center. Figure 4.4 shows RoR profiles with quantum of generation estimated by FY 2087/88. These profiles capture the strong seasonal nature of RoR generation, with high availability (90 - 95%) in wet months when river discharge is abundant and significantly reduced availability (15 - 35%) in dry months when river flows diminishes. The hourly output within a given day is relatively stable because RoR plants lack significant storage capability and operate nearly continuously at available flow. This makes RoR generation a dependable contributor to the systems base load during wet months, but conversely a limiting factor during the dry season when river flow sharply decreases. The variability of RoR output is one of the primary drivers behind Nepals pronounced seasonal surplus and deficit pattern, underscoring the importance of complementary generation sources and strategic operational scheduling.

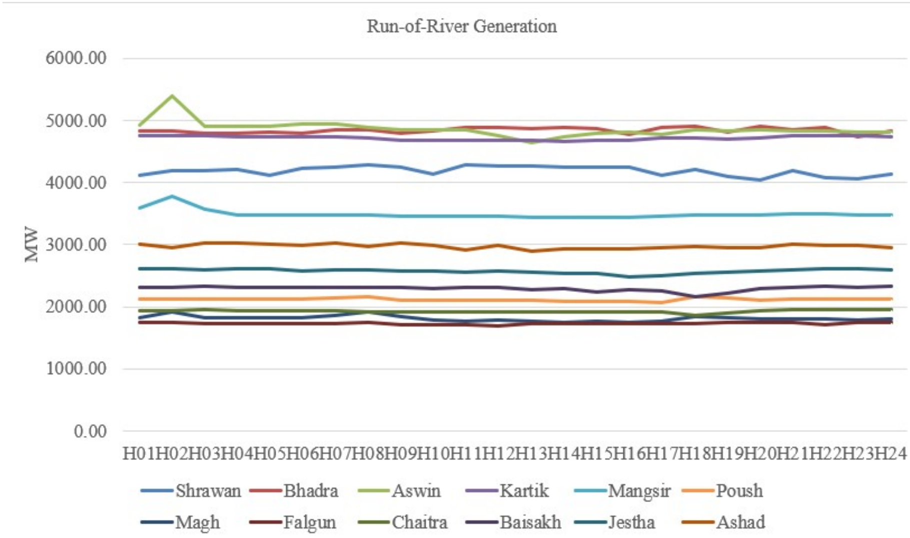

Figure 4.4: RoR Generation Capture by FY 2087/88

4.3.3 Peaking Run-of-River Generation

Peaking Run-of-River (PRoR) hydropower plants were modeled to reflect their unique operational flexibility arising from limited poundage capacity. Unlike conventional RoR plants, PRoR stations can store water for several hours, allowing them to strategically release stored water during specific periods of the day. Two operational cases were examined: Case 1, in which PRoR plants are scheduled during Nepal's evening peak demand hours, and Case 2, in which dispatch is aligned with the highest market prices hours in the Day-Ahead Market (DAM). In both scenarios, PRoR plants typically operate for four to six hours at or near full capacity, substantially enhancing system reliability during critical periods. Under Case 1, PRoR output significantly reduces evening deficits during dry months, while Case 2 enhances export revenue by targeting high-priced hours, particularly in wet months. The flexible nature of PRoR generation therefore plays a pivotal role in managing temporal mismatches between supply and demand while, improving the economic efficiency of cross-border electricity trade.

4.3.4 Storage Hydropower Generation

Storage hydropower plants were modeled using AFs that account for reservoir storage capabilities, allowing for controlled and flexible dispatch across all hours of the day. Unlike RoR and PRoR plants, storage stations can shift generation from low demand periods to high demand or high priced time slots, making them essential for managing both seasonal shortages and hourly peak deficits. Their ability to provide firm capacity is especially critical during the dry months when other hydropower sources face limited availability. In this study, storage plants were dispatched strategically to complement PRoR operation under both Case 1 and Case 2 schedules. During dry-season evenings, storage output plays a crucial role in mitigating deficits, while in wet-season operations, storage dispatch aligns with high-price export hours to maximize revenue. Although storage hydropower represents only about 3% of Nepals installed capacity mix, its contribution to system stability and export potential is disproportionately large, highlighting the need for expanding reservoir-based hydropower in future planning.

4.4 National Energy Surplus and Monthly Balance

The national energy balance for FY 2087/88 was evaluated by comparing the projected annual generation of 42,501 GWh with the estimated annual demand of 24,957 GWh, as depicted in Figure 4.5. This resulting in a substantial annual surplus of approximately 17.5 TWh. This surplus arises primarily due to the large scale commissioning of hydropower projects in the coming years, especially RoR and peaking RoR plants that produce abundant energy during the monsoon season when river flows are at their highest. This situation is even hike by integrating Solar projects which adds additional energy during sunshine hours. The magnitude of this surplus underscores the structural characteristics of Nepal's hydropower dominated supply mix, where generation is heavily influenced by seasonal hydrology rather than constant year round demand requirements. The seasonal distribution of this surplus is an essential factor in planning export strategies, transmission adequacy, and operational scheduling of flexible hydropower assets.

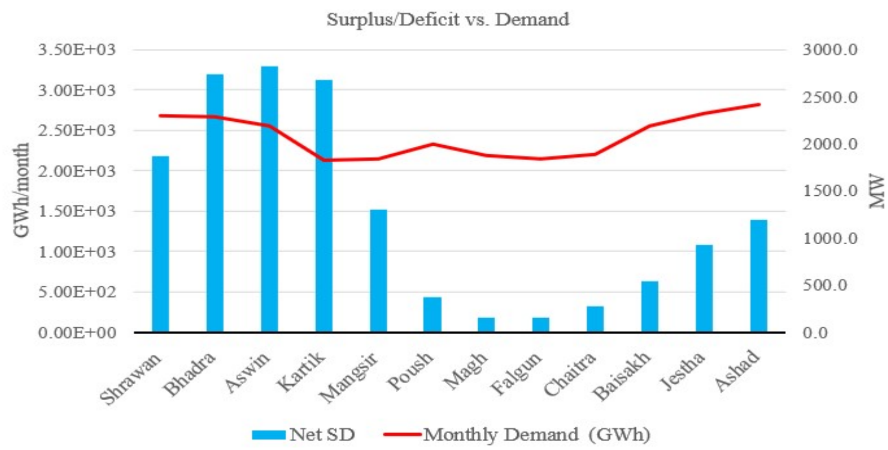

Figure 4.5: Monthly Energy balance Vs Demand curve

A clear seasonal trend emerges when examining monthly energy balances; wet months consistently generate large surpluses, while dry months exhibit localized deficits. During the wet season (Jestha to Kartik), high river discharge allows RoR and PRoR plants to operate near full capacity, and solar output also increases during midday hours, resulting in surplus energy that often exceeds 2,000 MW and reach up to 5,000 MW during peak production hours. These surpluses persist across most hours of the wet season, presenting significant opportunities for cross-border export. However, without sufficient transmission capacity, a portion of this energy remains unexportable, leading to curtailment. Thus, while the wet season provides an abundance of renewable energy, it also highlights the operational challenge of evacuating and monetizing the surplus.

In contrast, the dry season (typically mid-Mangsir to mid-Jestha) is marked by reduced hydrological inflows, causing run-of-river plants to operate at only 20 - 35% of their rated capacity. As a result, several hours especially in the evening peak period experience energy deficits even after contributing from PRoR and Storage hydropower dispatch. These deficits are generally modest, requiring an estimated annual import of 0.44 TWh to maintain system reliability. The interplay between reduced RoR output and increasing winter demand creates a seasonal stress on the system, but the presence of PRoR and Storage hydropower substantially mitigates the severity of these deficits. In particular, storage plants play a pivotal role in supplying firm energy during hours when river based hydropower performs the weakest.

The monthly balance analysis also illustrates how solar generation contributes to daily and seasonal dynamics. Solar PV adds significant energy during midday hours across all months, especially during dry winter periods when skies are clearer and solar irradiance is higher. Although solar cannot directly support evening peak loads, it reduces daytime demand on hydropower, thereby allowing PRoR and Storage plants to conserve poundage or reservoir water for later use. During wet months, solar energy compounds the midday surplus, further expanding the exportable energy window but also increasing potential curtailment if transmission capacity remains limited.

The relationship between monthly generation and demand demonstrates that Nepal's energy system is fundamentally characterized by wet-season surplus and dry-season deficit patterns. This seasonal imbalance is the defining factor in determining annual export potential, transmission requirements, and economic outcomes of different operational strategies. Monthly surplus profiles also reveal the periods when export-oriented dispatch (Case 2) becomes more valuable, as market aligned scheduling better captures high price hours and reduces underutilized surplus compared to a purely demand oriented approach. Overall, the monthly analysis highlights both the opportunities and challenges inherent in Nepal's future power system, emphasizing the need for strategic generation scheduling and expanded cross-border transmission infrastructure to effectively harness the nations hydropower potential.

4.5 Operational Strategies for PRoR and Storage Hydropower

The dispatch of flexible hydropower resources, specifically, PRoR and Storage plants plays a important role in shaping Nepal's hourly energy balance, export capability, and financial outcomes. Unlike RoR plants whose output is determined strictly by river inflows, PRoR and Storage facilities can shift generation to selected hours, enabling strategic alignment with either domestic system needs or external market opportunities. Accordingly, this study evaluates two distinct dispatch strategies: *Case 1: Demand Following Scheduling* and *Case 2: Market Price Based Scheduling.* Both strategies use the same hourly availability factors and generation potential but differ fundamentally in the criteria used to select the hours in which PRoR and Storage plants operate at or near full capacity.

4.5.1 Case 1: Demand Following Scheduling

Here, PRoR and Storage generation is dispatched with the primary objective of satisfying domestic demand during critical peak hours and minimizing the need for imports, particularly in dry season evenings when hydropower availability is lowest. The dispatch schedule is therefore derived directly from the hourly demand curve, such that generation from flexible units is prioritized during the highest demand hours of each day. In the our context, these periods consistently fall between 17:00 and 21:00 hours, corresponding to the evening peak observed across all months.

The hourly PRoR dispatch under Case 1 as shown in Figure 4.6 clearly demonstrates this demand following behavior. Graph below illustrate respective demand and PRoR scheduled profile for wet and dry month. During high inflow months such as Shrawan, Bhadra, Aswin, and Kartik, PRoR generation often reaches its rated value of 2409.5 MW during evening hours (H19 - H22), reflecting its role in meeting domestic peak load. In these months, PRoR also dispatches during late morning and mid afternoon hours to balance daytime demand but remains most consistently utilized during evening peaks. During low inflow dry season months Mangsir through Chaitra, the number of hours in which PRoR can operate at full output is reduced due to limited poundage availability. Still, the pattern persists: PRoR output is concentrated during evening peak hours, and many early morning and late night hours (H01 - H05 and H23 - H24) show zero dispatch, consistent with domestic demand prioritization.

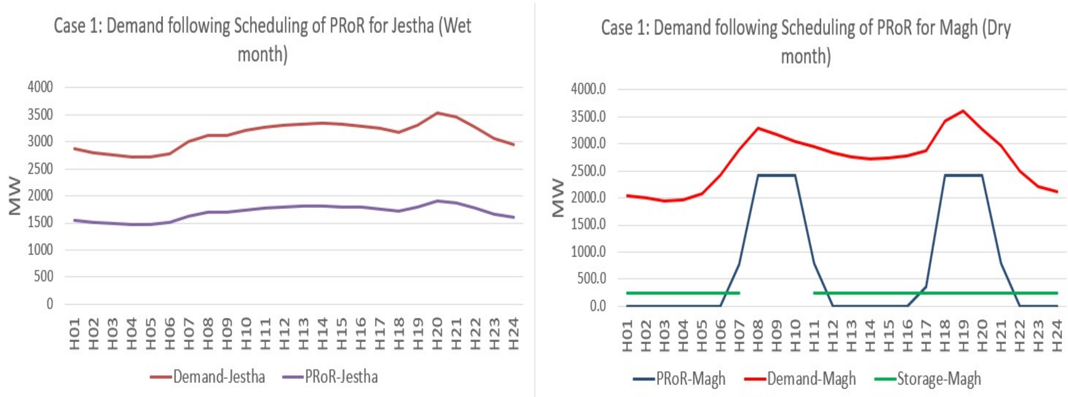

Figure 4.6: PRoR Storage schedule for Wet and Dry months following Demand profile

Storage dispatch under Case 1 follows a similar logic but is constrained by reservoir energy availability. Storage operation begins only in the extreme dry months (Poush to Baisakh), where deficits are most pronounced. Storage plants dispatch at approximately 246 MW during the evening peak hours (H17 - H22), and in some months, also during early morning winter peaks (H01 - H06). No storage generation occurs during wet-season months because domestic demand can be fully met by RoR and Solar generation. This strategic allocation preserves stored water for reliability in critical hours significantly reducing import reliance.

4.5.2 Case 2: Market Price Based Scheduling

Case 2 adopts a fundamentally different approach by aligning the dispatch of PRoR and Storage plants with high price intervals in the DAM. Instead of following the domestic demand curve, the model ranks each hour of the day by DAM price for every month and allocates PRoR and Storage generation to the highest priced hours, provided that sufficient water availability exists. This strategy thereby shifts flexible hydropower generators into hours that maximize export revenue while still maintaining adequate domestic supply.

The hourly PRoR dispatch order under Case 2 illustrated in Figure 4.7, resulting behavior following the ranked market price. Unlike Case 1, where PRoR output is concentrated in evening hours, Case 2 spreads PRoR dispatch across a wider range of hours that correspond to market price peaks. In wet season months such as Shrawan and Bhadra, PRoR dispatch reaches full output (2409.5 MW) for a significant number of hours spanning early morning, midday, and evening, reflecting the multiple price spikes observed in the DAM during these periods. In some months (e.g., Kartik and Aswin), PROR operates at full output for nearly 20 hours out of 24 hours, demonstrating both the abundant water availability and the profitability of exporting during most hours. During the dry season, PRoR output is more selective, prioritizing the limited poundage capacity for six hours with the highest price signals, resulting in variable dispatch profiles that differ markedly from demand-based scheduling.

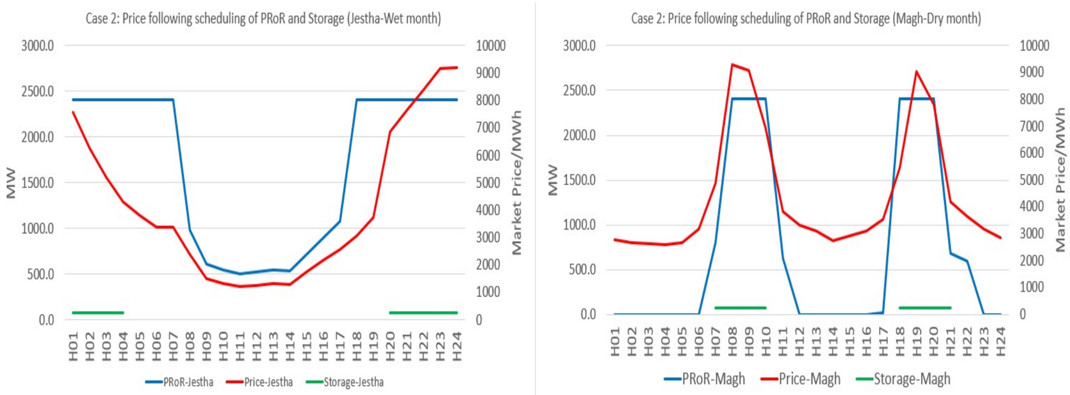

Figure 4.7: PRoR and Storage schedule for Wet and Dry months following Market Price

Storage dispatch under Case 2 also aligns with high-price export windows. Storage plants release water primarily during the highest-priced 5 to 7 hours rather than solely during domestic peaks. For example, in Bhadra under Case 2, storage dispatch occurs in scattered high value hours rather than in a single consolidated evening block, highlighting its role in maximizing export revenue. In dry season months like Poush, Magh, and Falgun, storage plant is selectively operated during high price hours, and domestic deficit is compensated through imports while storage is reserved for profitable export windows. This outcome demonstrates with the trade-off inherent in market-based scheduling, higher export revenue is achieved at the expense of slightly increased import dependence, although the overall import requirement remains low in annual terms.

4.6 Hourly Surplus Analysis

The hourly surplus analysis provides a detailed understanding of how the Integrated Nepal Power System (INPS) balances supply and demand across all 8,760 hours of the year. Figure 4.8 and 4.9 shows the surplus or deficit patterns on average hourly basis under two cases discussed in section 4.5. Tables attached in the **Appendix C A.1 and A.2** represents hourly surplus/deficit observed by FY 2087/88. By integrating hourly generation profiles from RoR, PRoR, Storage, and Solar with the hourly demand matrix, the model identifies periods in which the system experiences excess energy that can be exported, as well as hours of deficit that may require support from storage or limited imports. This granular analysis is essential because Nepal's hydropower resources are highly sensitive to seasonal hydrology and follow a distinct daily pattern that cannot be fully understood using only monthly or annual averages. Hourly modeling thus captures intra-day variations and highlights the operational challenges and opportunities associated with dispatching a predominantly hydropower based dominated system.

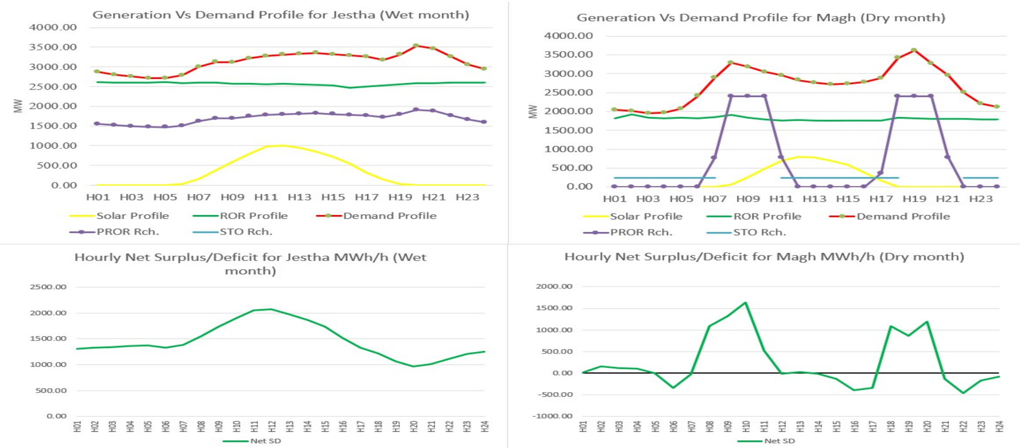

Figure 4.8: Hourly Surplus under Case 1 for representative months Jestha and Magh

A clear distinction emerges between wet-season and dry-season hourly behavior. During the wet months, typically Jestha to Kartik, high river inflows enable RoR and PRoR plants to operate at or near their maximum available capacity. When combined with midday solar generation, the system often experiences significant surplus levels exceeding 2,000 MW during daylight hours. This surplus remains consistent during most hours of the day, aside from minor variations caused by solar availability. Evening hours still exhibit surplus during these months because hydrological availability remains strong and demand does not rise enough to fully absorb the high generation levels. The wet-season surplus is therefore both sustained and substantial, creating considerable opportunities for cross-border energy exports provided that transmission capacity is sufficient.

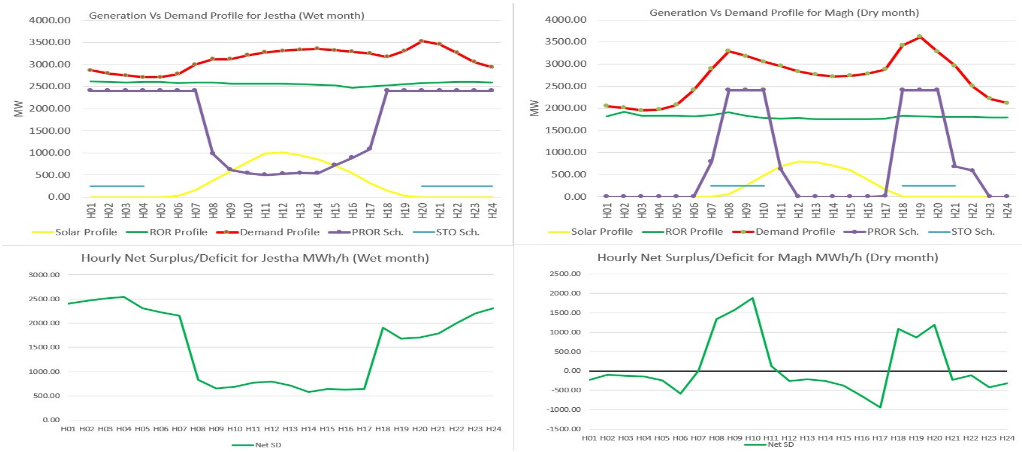

Figure 4.9: Hourly Surplus under Case 2 for representative months Jestha and Magh

In contrast, the dry season hourly analysis reveals several hours primarily during the evening peak where demand exceeds available supply from RoR and solar sources. During these months, river discharge declines sharply, causing RoR generation to drop to 20 - 35% of installed capacity. As evening demand increases and solar output falls to zero, the system becomes dependent on PRoR and storage units to fill the gap. PRoR plants, with their limited pondage, help significantly reduce deficits by generating during selected peak hours, while storage hydropower provides firm energy when needed. Despite these contributions, a residual deficit persists during 3 to 6 peak hours on the driest days of the year, resulting in the need for modest imports totaling approximately 0.44 TWh annually. This illustrates that even with significant hydropower expansion, seasonal hydrology continues to impose structural constraints on achieving full energy independence in every hour of the year.

Solar generation plays a nuanced role in shaping hourly surpluses however, with higher penetration level it could be observed clearly in shaping hourly surplus.while solar does not contribute during peak evening demand, its substantial production during midday hours increases surplus levels and can reduce the burden on hydropower resources earlier in the day. In dry season, this midday solar contribution is particularly beneficial, as it allows PRoR and storage plants to conserve water for evening peak periods. Conversely, during the wet season, high solar generation often coincides with already abundant hydropower availability, amplifying midday surpluses that may exceed the capacity of cross-border transmission lines, thereby increasing the likelihood of curtailment if export transmission line corridors are constrained.

The hourly surplus analysis also highlights the impact of the two dispatch scenarios for PRoR and Storage plants. Under Case 1, PRoR and Storage units are dispatched primarily to align with domestic evening peak demand, which effectively minimizes local deficits but may not fully exploit the value of wet-season surpluses. In contrast, Case 2, which coordinates dispatch with the highest priced export hours in the Day Ahead Market (DAM), shifts more energy towards export during profitable hours, especially during the wet season. This strategy reduces the volume of underutilized surplus, improves revenue generation, and slightly increases the system's ability to maintain balance during dry season peaks through more optimal water use. The contrast between two cases underscores the importance of a dynamic operational strategy that responds to both domestic needs and external market signals.

Overall, the hourly surplus analysis reveals that Nepal's future power system will experience prolonged periods of abundant energy, interspersed with short, predictable deficit windows driven by seasonal hydrology and daily demand patterns. These insights reinforce the critical need for expanded cross-border transmission capacity, enhanced storage capability, and market responsive dispatch strategies to maximize the economic and operational benefits of Nepal's evolving energy landscape.

4.7 Integration of Pumped Storage Hydropower (PSH) and It's Impact on Surplus and Revenue

The integration of Pumped Storage Hydropower (PSH) within Nepal's generation framework introduces a critical element of flexibility that enhances the operational efficiency of the renewable dominated power system. PSH provides the capability to store surplus energy during low demand or low price periods and release it during peak demand or high price hours, thereby improving grid stability, maximizing utilization of renewable generation, and increasing overall system profitability. This section presents the modeled results and analysis of PSH integration under the projected system conditions of FY 2087/88. The analysis presented in this section builds upon the methodology described in Section 3.4, where the PSH scheduling logic, operational equations, and decision key $Pump_{\text{key}}[m, h]$ were developed. Pump operational logic table is included in **Appendix D A.1**.

4.7.1 PSH Projects Considered

Three potential PSH projects were selected for inclusion in the model, representing a total installed capacity of 928.5 MW. These projects were identified from the Department of Electricity Development (DoED) pipeline based on their technical feasibility conducted by the NEA. This study highlights impact of PSH on surplus and revenue at system level. The selected projects are summarized in Table 4.3. These three PSH projects were modeled collectively to represent national level pumped storage capability. Their combined capacity enables the absorption and re-dispatch of approximately 930 MW of energy on an hourly basis.

Table 4.3: List of PSH identified for implementation

Project Name	**Capacity MW**	**License No.**	**Promoter**
Syarpu Lake Pump Storage Hydroelectric Project	334.0	1250	Nepal Electricity Authority
Hulingtar Dumkin Pumped Storage Hydropower Project	494.50	1443	Nepal Electricity Authority
Kulekhani Sisneri Pump Storage Hydroelectric Project	100	1452	Nepal Electricity Authority

4.7.2 Operational Characteristics and Seasonal Behavior

The operational performance of the Pumped Storage Hydropower (PSH) system was evaluated on an hourly basis to analyze its interaction with seasonal generation patterns and market responsive dispatch. The detailed scheduling logic and governing equations including the derivation of $Pump_{\text{key}}[m, h], E_{\text{pump}}[m, h], E_{\text{pump,stored}}[m, h]$, and $E_{\text{pump,Gen}}[m, h]$ have been described in Section 3.4. This subsection focuses on the system's observed behavior derived from the simulated results. Operational algorithm for PSH is tabulated and included in **Appendix D A.1**

Figure 4.10 illustrates the monthly PSH operation profiles, depicting pumping and generation cycles for representative months throughout the fiscal year. In each subplot, the stacked blue and yellow bars represent the energy utilized for pumping from RoR and solar sources, respectively, while the red line indicates hourly PSH generation output. The figure clearly highlights the temporal coordination between surplus renewable availability and market-based generation scheduling.

During the wet months (Jestha – Mangsir), abundant RoR discharge and high solar irradiation create significant mid-day surpluses. The PSH system operates predominantly in pumping mode ($Pump_{\text{key}}[m,h] = 1$), as shown by continuous blue and yellow stacked bars across daylight hours. In months such as Shrawan, Bhadra, and Ashoj, nearly the entire 928.5 MW pumping capacity is utilized between 08:00 16:00 hours, absorbing excess energy that would otherwise be curtailed. The presence of yellow $Solar_{\text{pump}}$ fractions in these months indicates direct use of surplus solar energy for pumping, with RoR generation contributing the remainder. This coordinated absorption minimizes spillages and mitigates transmission congestion during wet season peaks.

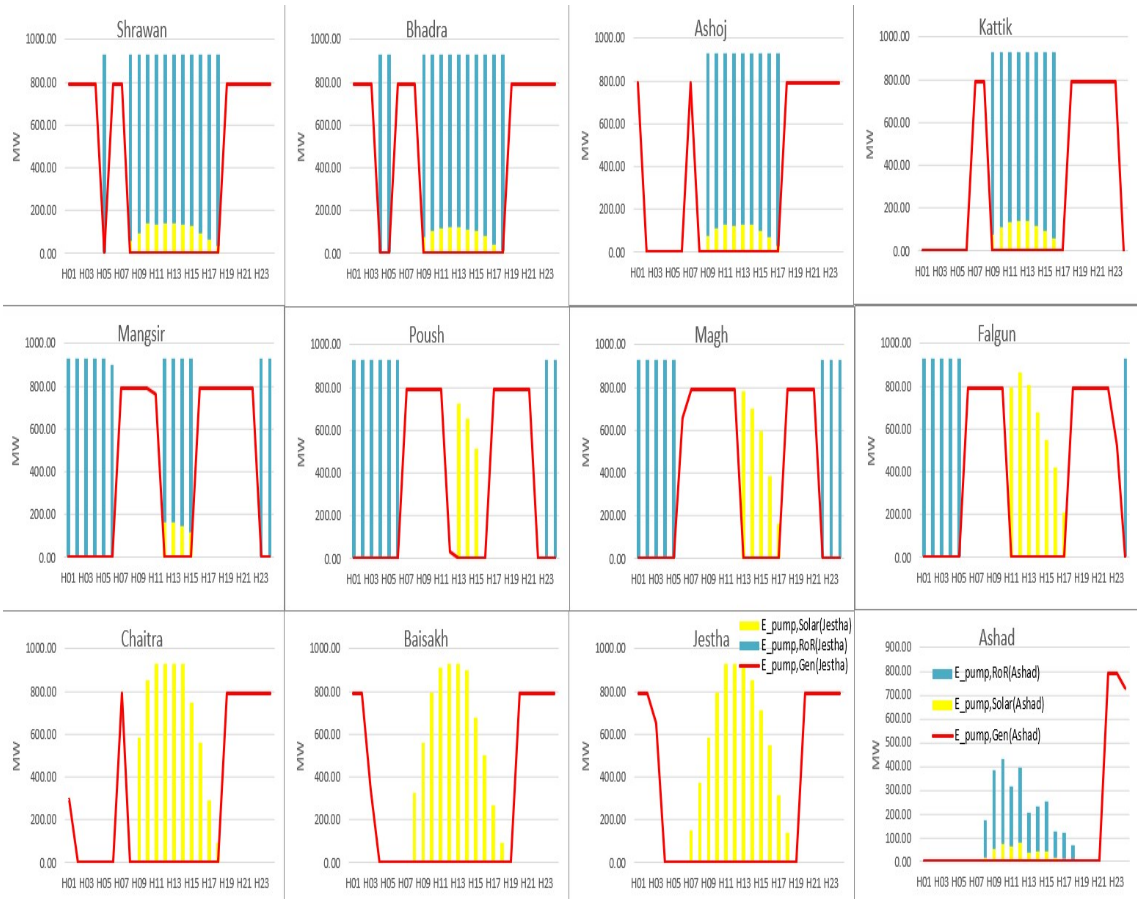

Figure 4.10: Monthwise Operation Profile of Pumped Storage Hydropower

As inflows decline toward the dry season (Mangsir – Jestha), PSH operation shifts toward generation mode ($Pump_{\text{key}}[m,h] = 0$), depicted by the red curves. In months such as Poush, Magh, Falgun, and Chaitra, generation is concentrated during morning and evening hours, coinciding with high price periods in the Day-Ahead Market. The stored energy from previous low price pumping hours is dispatched to meet domestic demand or to capture export opportunities. The plots for Chaitra, Baisakh, and Jestha particularly demonstrate this behavior showing pumping around midday (high solar availability) and generation during early-morning and late-evening peak hours. This temporal energy shifting directly contributes to increased export potential and higher system revenue.

The graphs also reveal the cyclic operational nature of PSH throughout the year. In wet months, PSH acts primarily as a load, flattening the net generation curve by absorbing midday surpluses. Likewise in dry months, it behaves as a peaking generator, stabilizing supply during demand intensive hours. Such operation enhances system flexibility, improves renewable energy utilization, and reduces curtailment especially during Shrawan, Bhadra, Ashoj, and Kartik, when RoR and solar generation reach seasonal maxima.

Overall, the monthly operation patterns confirm that PSH effectively functions as an energy-shifting mechanism within the integrated system. It not only supports grid balancing and reliability but also maximizes economic returns by aligning dispatch with market price signals. The modeled behavior validates the PSH integration strategy and demonstrates its suitability for Nepals future grid characterized by high solar-hydro complementarity.

4.7.3 Energy Balance and Conversion Efficiency

The integration of Pumped Storage Hydropower (PSH) introduces a dynamic mechanism of temporal energy reallocation aimed primarily at maximizing economic returns rather than minimizing surplus variation. Unlike conventional storage systems that seek to flatten generation profiles, the operational strategy adopted here prioritizes generation during high-price periods in the day-ahead market (DAM) to enhance export revenue. Consequently, the effect of PSH on the national energy balance is observed both in terms of marginal energy losses from conversion and substantial increases in market-based income.

Figure 4.11 compares hourly surplus with and without PSH integration for representative wet and dry season months Bhadra and Magh, respectively. In Bhadra (wet season), the surplus curve with PSH (red line) shows deliberate withdrawal of energy during mid-day hours (when pumping occurs) and higher surplus during evening hours (when PSH re-generates). In contrast, the surplus without PSH (blue line) remains relatively flat, reflecting the passive dispatch of RoR and solar generation without storage.

Similarly, in Magh (dry season), PSH operation leads to distinct dual peaks corresponding to the morning and evening high price hours. The system surplus rises sharply during these intervals, demonstrating that stored energy is strategically released to coincide with favorable market conditions. Although this behavior increases instantaneous surplus at peak hours, it translates directly into higher exportable energy and financial returns rather than technical inefficiency.

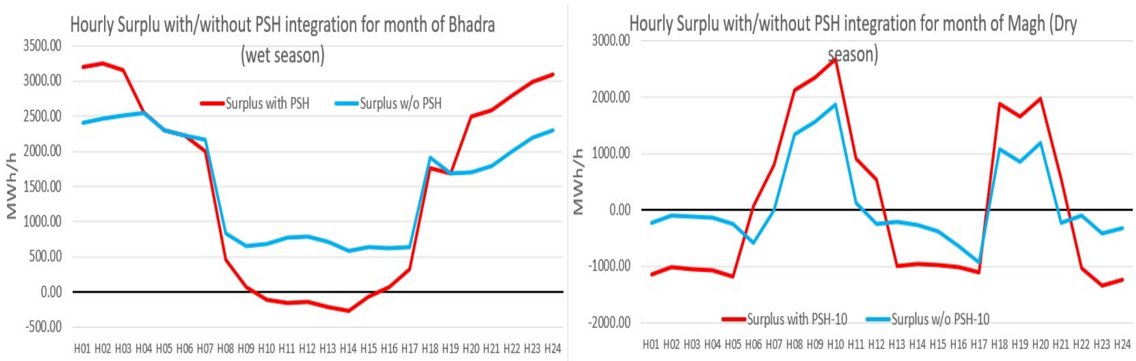

Figure 4.11: Hourly Surplus with and Without PSH Integration

Quantitatively, total annual surplus after PSH integration decreased slightly from 17,500 GWh to 17,078 GWh, implying an energy loss of 421.77 GWh due to the 85% round-trip efficiency of the pump–generation cycle. However, this small reduction in net energy is offset by a significant revenue gain, from NPR 113.42 billion to NPR 127.68 billion with PSH operation an increase of approximately 12.6 %. This demonstrates that PSH operation is economically superior when market price differentials between off–peak and peak hours are large.

The hourly results thus reveal two key implications: First, revenue maximization by strategically placing PSH generation at high price, thereby improving the system's marginal revenue yield. Secondly, PSH operation alter surplus dynamics by redistributing generations creating localized peak during high value hours. While this could raise curtailment risks if export capacity is constrained, it also provides an opportunity to monetize previously underutilized energy through targeted dispatch scheduling.

4.8 Zone-Wise Generation, Surplus, and Transmission Limits

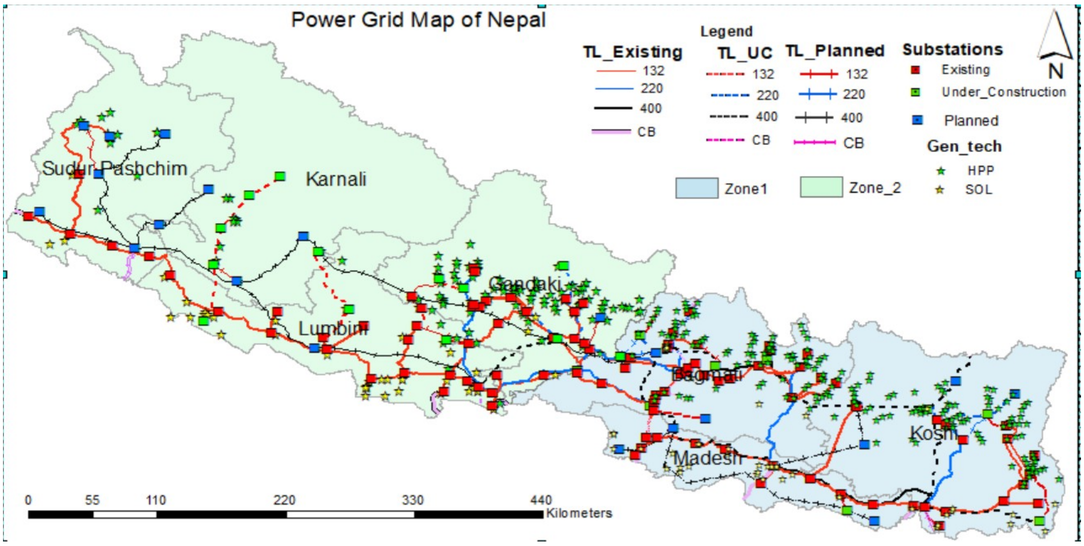

Figure 4.12: Power Map showing Generation hub, Transmissions including CB infrastructures.

The zone-wise analysis provides a spatial understanding of Nepal's generation distribution, regional surplus patterns, and the constraints imposed by available cross-border transmission infrastructure. For this study, the Integrated Nepal Power System (INPS) is divided into two operational and transmission planning zones based on geographic proximity, load centers, and the availability of high voltage cross border transmission line. Power grid map developed in ArcGIS 10.8 distinctly shows existing, under-construction, and planned transmission infrastructures along with spatial distribution of generators as depicted in Figure 4.12. Zone 1 covers the Koshi, Madesh, and Bagmati provinces, while Zone 2 includes Gandaki, Lumbini, Karnali, and Sudurpaschim provinces. This division is particularly important because the hydropower expansion in Nepal is not evenly distributed across regions, and export pathways are heavily dependent on the corridor-specific transmission limits to India. A zone-wise interpretation therefore allows for a clearer assessment of evacuation bottlenecks, localized surpluses, and the potential challenges in maximizing Nepal's export revenue.

Zone 1, comprising the eastern and central regions, is projected to contribute the majority of Nepal's future electricity generation, accounting for nearly 68% of the total install capacity by FY 2087/88. Installed capacity and Surplus/deficit portfolio by zone wise is depicted in respective Figure 4.13 and Figure 4.14. This region hosts several large and medium-sized hydropower projects, many of which are run-of-river schemes with substantial wet season generation potential. As a result, Zone 1 produces an estimated 12.8 TWh of surplus energy annually, making it the dominant contributor to Nepal's exportable power. However, this high concentration of generation also places significant pressure on the existing and planned cross-border transmission links in the eastern corridor. The major transmission assets serving this zone include the Dhalkebar–Muzaffarpur 400 kV line, currently Nepal's most important export corridor with a capacity of up to 1700 MW under N-1 contingency (thermal capacity of double circuit 3393 MW), and lower-voltage links such as the Kusaha–Kataiya and Raxaul–Parwanipur 132 kV lines. Under the N-1 security criterion, the effective export capacity from Zone 1 is limited to approximately 1900 MW, which is significantly lower than the surplus available during peak wet-season hours. Consequently, Zone 1 becomes the primary site of curtailment during high-generation periods, highlighting the urgent need for additional 400 kV corridors in the east to relieve this chronic congestion.

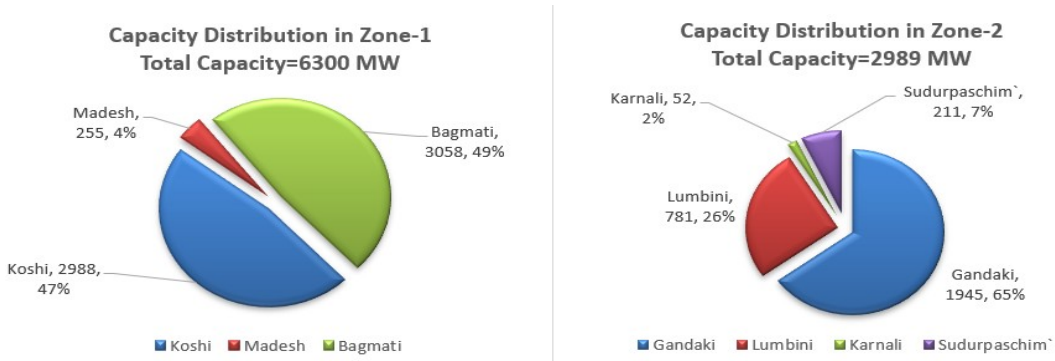

Figure 4.13: Installed capacity in respective Zone 1 and Zone 2.

Zone 2 covers the western, mid and far western regions, that contributes around 32% of national generation and produces approximately 4.7 TWh of annual surplus. Although this surplus is smaller compared to Zone 1, Zone 2's geographic and infrastructural characteristics make it strategically valuable for future export expansion. The region is supported by several cross-border transmission links, including the Mainahiya-Sampatiya 132 kV, Gandak-Ramnagar 132 kV, and Tanakpur-Mahendranagar 132 kV lines. More importantly, Zone 2 is the focus of planned expansion through high capacity 400 kV corridors such as the Butwal-Gorakhpur (BG) 400 kV line and the proposed Lamki-Bareilly 400 kV line. These future assets position Zone 2 as long-term export hub with untapped generation potential. However, under current development timelines, only the Butwal-Gorakhpur link is expected to be operational by FY 2083/84, with combined capacity Under the N-1 security criterion, the effective export capacity from Zone 2 is limited to approximately 2100 MW. Combined capacity from zone 1 and zone 2 will not fully resolve national level bottlenecks because the majority of surplus energy originates from Zone 1 rather than Zone 2.

Figure 4.14: Surplus and Deficit plot in respective Zone 1 and Zone 2.

The combined zone-wise analysis reveals a critical structural challenge for Nepal's power system with the geographical mismatch between generation surpluses and transmission capacity availability. While Zone 1 produces the bulk of surplus energy, its export capacity is severely constrained, leading to substantial curtailment of 1.03 TWh equivalent generation during the wet season. Meanwhile, Zone 2, though less congested, lacks sufficient generation volume to fully utilize its anticipated transmission expansion. This imbalance underscores the need for a coordinated national transmission strategy that not only expands cross-border links but also strengthens the east–west backbone of the domestic grid to disperse surplus generation from Zone 1 toward underutilized export corridors in Zone 2.

Overall, the zone-wise generation and transmission assessment highlights both opportunities and limitations in Nepal's emerging power export landscape. The expected generation boom by FY 2087/88 will create a sizable national surplus, but realizing its full economic value depends on overcoming regional bottlenecks, accelerating cross-border transmission projects, and aligning domestic grid development with export potential. Without these interventions, Nepal risks continuing to curtail significant amounts of renewable energy, especially in Zone 1, despite the availability of promising export markets.

4.9 Transmission Adequacy and Export Limitations

Transmission adequacy plays a central role in determining the extent to which Nepal can realize the economic value of its growing hydropower surplus. Although domestic generation capacity is projected to exceed national demand by a wide margin by FY 2087/88, the ability to export this surplus hinges on the availability, reliability, and operational limits of Nepal's cross-border transmission infrastructure. The analysis conducted in this study evaluates transmission adequacy under the N-1 security criterion, which ensures that the system can continue operating reliably even in the event of an outage of the largest transmission element. Calculation of transmission capacity under N-1 contingency is attached in **Appendix E**. Under these conditions, Nepal's total effective cross-border export capacity is estimated at 4000 MW, primarily facilitated through the Dhalkebar-Muzaffarpur (400 kV), Butwal-Gorakhpur (400 kV), and selected 132 kV corridors. While this capacity is substantial relative to past levels, it is significantly lower than the 5,200 MW of hourly surplus observed during peak wet season periods, indicating a structural mismatch between available generation and export capability. List of operation, construction, and planned cross border transmission lines are presented in the Table 4.4. A detailed examination

Table 4.4: CBTL Projects status in Zone 1 and Zone 2

Project Name	**Ckt Km**	**No. Ckt**	**Zone**	**Pthem. MW**	**Status**
Dhalkebar-Muzaffarpur 400 kV	78	Double	Zone 1	3400	Existing
Kusaha-Kataiya 132 kV	15	Double	Zone 1	160	Existing
Raxual-Parwanipur 132 kV	32	Double	Zone 1	160	Existing
Mainahiya-Sampatiya 132 kV	56	Double	Zone 2	160	Existing
Tanakpur-Mahendranagar132 kV	12	Single	Zone 2	90	Existing
Gandak-Ramnagar 132 kV	–	Single	Zone 2	100	Existing
Butwal-Gorakhpur 400 kV	18	Double	Zone 2	3400	Construction
Lamki (Dodhara)-Bareli 400 kV	70	Double	Zone 2	3400	Planned
Inaruwa-Purnea 400 kV	50	Double	Zone 1	3400	Planned
Nepalgunj-Nanpara 132 kV	33	Double	Zone 2	160	Construction

of hourly export requirements reveals that transmission constraints are most severe during the monsoon months, when hydropower generation reaches its annual peak. During these periods, RoR and PRoR plants generate at high capacity across most hours, and midday solar production adds an additional layer of surplus. The hourly model shows that surplus often exceeds the export limit for extended durations, particularly between 10:00 and 16:00 hours. This leads to considerable curtailment of renewable energy that could otherwise be exported if sufficient transmission corridor were available. The situation is further exacerbated in Zone 1, which houses the majority of generation capacity but relies heavily on a single major export corridor the Dhalkebar-Muzaffarpur 400 kV line. Under N-1 conditions, this corridor alone accounts for nearly half of effective export capacity. Any temporary outage or reduced availability in this corridor directly limits export volumes and increases curtailment risk during high-generation periods.

Although the commissioning of Butwal-Gorakhpur 400 kV line marks a significant milestone in expanding Nepals export capability, its immediate impact is constrained by the relatively lower generation concentration in Zone 2. Under the projected system conditions of FY 2087/88, Zone 2 contributes only about one-third of the national surplus, meaning that even with additional transmission capacity available in the west, the majority of exportable energy remains tied to Zone 1 and its congested eastern corridors. This regional imbalance reinforces the need for strengthening east-west domestic transmission backbone to facilitate the transfer of surplus energy from the eastern hydropower clusters to the western export nodes. Without such internal grid reinforcement, new cross-border lines in Zone 2 will remain underutilized, limiting the country's ability to achieve full export potential.

The consequence of these transmission constraints is reflected in the significant amount of energy curtailment observed in the model. Annual curtailed energy is estimated at 1.03 TWh, representing a substantial economic loss of approximately NRs 4.66 billion per year, calculated at prevailing export market prices. Curtailment occurs primarily during the wet season when production exceeds both domestic demand and available export capacity. While some level of curtailment is expected in RoR dominant systems, the magnitude observed in Nepals case indicates insufficient transmission investment relative to the anticipated growth in hydropower generation. Curtailment also reduces overall system efficiency, undermines project revenues, and could potentially weaken investor confidence in the long-term stability of the export market.

In summary, the transmission adequacy assessment highlights a fundamental bottleneck in power export strategy. While the country is poised to generate substantial renewable energy surpluses, the existing and near-term transmission infrastructure is insufficient to evacuate these surpluses fully, leading to significant curtailment and revenue loss. To unlock the full economic potential of hydropower resources, strategic investments are needed in additional 400 kV corridors especially the Inaruwa-Purnea and Lamki-Bareli lines and in strengthening domestic eastwest transmission corridor. Enhancing transmission capacity, both cross-border and domestic, is essential for achieving long-term export growth, improving system flexibility, and ensuring the economic viability from rapidly expanding hydropower sector.

4.10 Export and Import Performance

The export and import performance for FY 2087/88 reflects the combined influence of seasonal hydropower availability, domestic load behavior, operational dispatch strategies, and cross border transmission constraints. Based on the hourly simulation, Nepal is projected to maintain a strong net export position, exporting approximately 17.98 TWh of electricity over the year while importing only 0.44 TWh to cover deficit hours during the driest months. This outcome underscores the countrys transition from a historically energy-deficient system to one characterized by substantial renewable energy surpluses, driven primarily by expanding hydropower capacity. However, the magnitude and timing of both exports and imports are shaped by a complex interaction between availability of generation, market conditions, and transmission infrastructural limitations, all of which influence the economic efficiency of the power system.

Electricity exports are heavily concentrated in the wet season, when hydropower generation from RoR and PRoR plants reaches its peak capacity. During these months, domestic demand is consistently exceeded by available supply across most hours of the day, enabling uninterrupted export throughout both peak and off-peak periods. The combination of high RoR output and strong midday solar generation further enhances exportable surplus during daytime hours. Export volumes remain high during evening hours as well, because hydrological conditions allow PRoR plants to continue operating at near-maximum capacity regardless of fluctuating demand. As a result, wet season export performance is largely constrained not by generation availability but by the limitations of cross-border transmission corridors, particularly in Zone 1, where congestion is most pronounced. The wet season export profile therefore mirrors the cumulative effect of abundant hydropower production and the physical bottlenecks in regional export infrastructure.

In contrast, the dry season presents a different operational landscape. During winter and dry months, the reduced discharge in river basins diminishes the output of RoR plants, while solar generation remains constrained to daylight hours and provides no contribution during the system's evening peak. PRoR and Storage plants partially compensate for these deficits through targeted peak hour dispatch, but their limited pondage and reservoir capacities cannot fully offset the seasonal imbalance. Consequently, several hours in the dry season evenings experience energy shortfalls that require modest imports to ensure system reliability and avoid load shedding. The total annual import requirement is estimated to 0.44 TWh which accounts relatively small compared to annual exports 17.98 TWh as depicted in Figure 4.15, yet it plays a vital role in maintaining supply adequacy during periods of constrained hydropower availability.

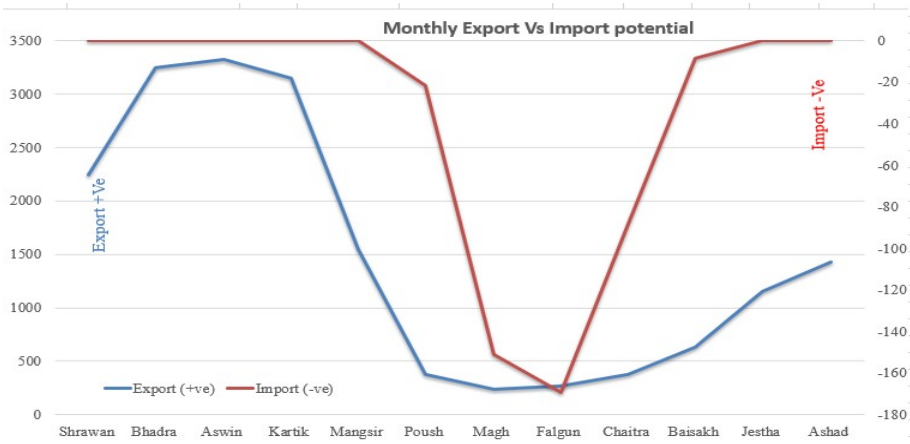

Figure 4.15: Monthly import export volume in GWh

The hourly modeling also reveals that the timing of exports is shaped by both domestic needs and external market opportunities. Under Case 1, exports occur whenever domestic demand is met and surplus capacity remains available, resulting in a more predictable export profile dominated by wet-season availability. Under Case 2, exports are strategically aligned with high price hours in the Day-Ahead Market of Indian Energy Exchange (IEX), enabling Nepal to increase revenue by dispatching flexible hydropower, particularly PRoR and Storage during periods of regional price spikes. While both cases maintain similar annual export volumes, the distribution and economic value of exports differ significantly. Case 2 produces a more financially optimized export schedule, enhancing the profitability of Nepals hydropower exports without compromising system reliability. Despite strong export performance, the analysis identifies several key limitations. Foremost among these is the mismatch between surplus generation and available export capacity, leading to significant curtailment of renewable energy that could otherwise be exported during profitable hours. Secondly, need for more storage with integration of Pump-Storage hydropower (PSH) deployment to achieve higher operational flexibility to reduce import and enhance the value of exports.

The integration of Pumped Storage Hydropower (PSH) further enhances Nepals export performance by enabling temporal arbitrage between low-price surplus hours and high-value export periods. As shown in Table 4.5, the system with PSH achieves an annual export of 18.64 TWh compared to only 17.98 TWh in the price-based case, while total imports increase marginally to 1.56 TWh. Monthly data indicate that PSH contributions are most pronounced from Falgun to Jestha, when conventional hydropower output declines; during these months, PSH generation maintains export flows even under reduced inflows. Conversely, limited off-peak imports appear during Poush–Falgun, corresponding to pumping operations that replenish the upper reservoir at low market prices. Overall, PSH integration demonstrates a reallocation of surplus energy toward high-value trading hours, improving utilization of existing renewable resources and strengthening Nepal's position as a net exporter. Although imports rise slightly due to pumping demand, the net energy exchange and total export revenue both increase substantially, confirming PSH's role as an economic catalyst that converts wet-season energy into strategic export power during periods of regional demand.

Table 4.5: Quantum of Electricity Export and Import in GWh with PSH Integration

Month	Export	Import	Month	Export	Import
Shrawan	2192.3	0.0	Magh	449.9	-411.6
Bhadra	3191.6	0.0	Falgun	467.8	-411.1
Ashoj	3287.8	0.0	Chaitra	529.3	-269.6
Kartik	3114.7	0.0	Baisakh	773.2	-181.1
Mangsir	1499.3	0.0	Jestha	1147.5	-29.6
Poush	570.5	-260.8	Ashad	1418.1	0.0

4.11 Financial Assessment of Export Strategies

The financial assessment of Nepals electricity export strategies evaluates the economic outcomes of the two operational dispatch cases: *Case 1: Demand Following*

Dispatch and *Case 2: Market Price Following Dispatch*, with the objective of determining which approach yields higher national revenue under the projected system conditions for FY 2087/88. While both strategies utilize the same generation portfolio and cross border transmission limits, they differ fundamentally in how flexible hydropower resources particularly PRoR and Storage plants are scheduled across the 8,760 hours of the year. As these technologies possess the capability to shift generation across time, their dispatch decisions directly influence the value captured in the Day-Ahead Market (DAM). Therefore, the financial analysis focuses not only on total energy exported but also on the timing of exports, which plays a decisive role in revenue generation.

Under the Case 1, the dispatch of PROR and Storage units is prioritized to meet domestic peak demand, especially during dry-season evening hours when run-of-river output declines and solar generation becomes unavailable. This approach minimizes Nepals dependence on imports and enhances internal system reliability. However, because PROR and Storage generation is consumed domestically during peak periods, the amount of energy available for export during high-price hours is reduced. As a result, although the total annual export volume remains substantial, the exports under Case 1 are often concentrated during hours with moderate regional market prices. The total annual revenue generated under Case 1 is estimated at NRs 98.4 billion, which reflects stable but suboptimal monetization of Nepals hydropower surplus.

In contrast, Case 2 strategically dispatches PRoR and Storage plants during hours with the highest DAM clearing prices, thereby aligning export behavior with market opportunities rather than domestic load patterns. This results in a redistribution of flexible hydropower generation into high value export windows, particularly during wet season midday and evening hours when price spikes are observed in the Indian market due to regional demand supply imbalances. By shifting generation into these profitable intervals, Case 2 increases the energy exported during peak price hours without significantly compromising domestic reliability, as Nepals surplus remains adequate during most hours of the year. The total annual revenue generated under Case 2 is NRs 113.4 billion, representing a notable improvement over Case 1 and yielding an annual incremental financial gain of approximately NRs 15 billion.

The integration of Pumped Storage Hydropower (PSH) further enhances the financial performance of Nepal's electricity export strategy by adding temporal flexibility to energy dispatch. As depicted in Figure 4.16 annual revenue increases from NRs

98.41 billion under demand-based dispatch to NRs 113.42 billion under price-based scheduling, and further to NRs 127.68 billion with PSH integration. This substantial improvement demonstrates that PSH enables effective energy arbitrageabsorbing surplus low-price energy during off-peak hours and releasing it during high-price export periodsthereby converting potential curtailments into profitable trade. Although total imports rise slightly due to pumping requirements, the overall export volume expands to 18.64 TWh, resulting in the highest revenue realization among all scenarios. The findings clearly indicate that PSH serves as a key mechanism for maximizing market-driven returns and improving the economic resilience of Nepals future hydropower-dominated energy system.

Figure 4.16: Revenue benefit with Price based schedule

Sensitivity analysis further demonstrates the importance of market timing in financial performance. A ś10% fluctuation in DAM prices produces a corresponding śNRs 11 billion variation in total annual revenue, highlighting the exposure of Nepals export earnings to regional market volatility. Under Case 2, the system is better positioned to capitalize on upward price swings, while Case 1 is more vulnerable to missed opportunities during peak price intervals. Therefore, the financial risk and reward scenario is significantly more favorable under market based scheduling, provided that system reliability is maintained through adequate storage allocation and strategic use of PRoR pondage. However, the financial assessment also underscores that export revenue is inherently constrained by cross-border transmission limitations, regardless of the chosen dispatch strategy. Even under market-based scheduling, the inability to fully evacuate surplus energy during high price hours limits the capacity to capture the benefits. As such, national focus should be in expansion of cross-border transmission corridors with additional 400 kV lines to ensure that high value export.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study analyzed Nepal's evolving power system under the projected conditions of FY 2087/88 to assess the magnitude, temporal behavior, and economic value of surplus hydropower generation with and without Pumped Storage Hydropower (PSH) integration. The study culminates in the development of an Excel-based analytical model capable of simulating multiple generation and demand scenarios under varying hydrological and market conditions. Designed with an hourly resolution, the model provides a realistic understanding of Nepal's energy balance dynamics, quantifying seasonal variations in surplus and deficit periods and their implications for domestic supply reliability and regional energy trade.

The modeling incorporated detailed operational behavior of Run-of-River (RoR), Peaking Run-of-River (PRoR), Storage, and Solar generation schemes, examining two operational strategies; case 1: demand following and case 2: market price following dispatches to evaluate their technical, operational, and financial implications. The subsequent integration of PSH was introduced as a flexibility mechanism to enhance surplus utilization, balance system operation, and maximize revenue through optimized cross border energy trade.

The results indicate that Nepal is projected to maintain a strong annual energy surplus of approximately 17.5 TWh by FY 2087/88, predominantly during the monsoon months, driven by RoR and PRoR hydropower generation. Seasonal analysis revealed distinct wet season surpluses and dry season deficits, confirming the necessity of flexible generation scheduling and expanded transmission infrastructure to effectively manage these fluctuations. The findings also highlight that, under current transmission configurations, particularly within the eastern corridor, significant curtailment risks could emerge unless high capacity 400 kV export lines are commissioned by the target year.

A comparative assessment of the two dispatch strategies revealed that market price following operation (Case 2) yields superior economic performance compared to demand following dispatch (Case 1). While Case 1 prioritizes domestic reliability and minimizes imports, Case 2 strategically schedules PRoR and Storage plants to operate during high-price hours in the Day-Ahead Market (DAM), enhancing export profitability. This optimization increases total export revenue from NRs 98.41 billion under Case 1 to NRs 113.42 billion under Case 2, marking a 13.2% financial improvement without compromising system stability. The analysis clearly demonstrates that the timing of exports, rather than total energy volume, determines financial efficiency in a hydropower dominated system connected to a regional market.

The integration of Pumped Storage Hydropower (PSH) further strengthens the financial and operational performance of Nepals energy system. By shifting surplus low cost energy to high price periods, PSH enhances temporal flexibility and mitigates curtailment. Although it incurs a minor round-trip energy loss of approximately 2.4% (421.8 GWh), the resulting annual export revenue rises to NRs 127.68 billion, representing a 12.6% gain over the price-based dispatch and 29.7% gain over demand following dispatch without PSH. The total exportable energy also increases to 18.64 TWh, demonstrating PSH's role as an energy arbitrage mechanism that transforms excess generation into high value exports. Operationally, PSH flattens midday surpluses through pumping and augments evening peaks through generation, aligning supply profile with regional demand and price signals, thus enhancing market integration and grid flexibility.

Zone-wise analysis identified the eastern and central corridors (Zone 1) as the dominant export regions, contributing over two thirds of the total surplus but constrained by limited 400 kV transfer capacity. The western region (Zone 2), with emerging storage and PSH potential, offers additional export flexibility and should be prioritized for future infrastructure expansion. Overall, the analysis confirms that Nepal will export approximately 17.98 TWh and import only 0.44 TWh annually, reaffirming its transformation into a net renewable energy exporter within South Asia.

This study confirms that Nepal's hydropower dominated grid, supported by flexible operation, market-oriented dispatch, and PSH integration, can transition from an energy surplus system to a value optimized power exporter. The analytical model and results demonstrate that with targeted investments in flexibility, infrastructure, and market mechanisms, Nepal is well positioned to become a regional leader in clean, reliable, and economically viable energy trade, fostering long-term sustainability and regional energy security.

5.2 Recommendation

Based on the findings of this study, several key recommendations are proposed to enhance Nepal's power system operation, surplus management, and cross-border trade efficiency by Fiscal Year 2087/88.

1. The foremost priority is the strengthening of cross border transmission infrastructure, particularly the completion and operationalization of high capacity 400 kV corridors such as Inaruwa–Purnea in zone 1, and Lamki–Bareilly in zone 2. These links are critical for unlocking full export potential and minimizing curtailment during the wet season when hydropower and solar generation are abundant. Parallel reinforcement of domestic 132 kV and 220 kV networks, adopting automation of substations, and system protection upgrades is equally important to support flexible generation dispatch and reliable inter-regional electricity transfers.

2. The integration of Pumped Storage Hydropower (PSH) is strongly recommended as a strategic measure to enhance system flexibility, balance hourly demand supply variations, and maximize export revenue. The study demonstrates that PSH can shift surplus low cost energy to high price hours, increasing export earnings by over 12 percent despite minor conversion losses. Early implementation of identified PSH projects like:- Syarpu Lake, Hulingtar–Dumkin, and Kulekhani–Sisneri should therefore be prioritized within the national generation expansion plan.

3. At the operational level, price based scheduling and market responsive dispatch mechanisms should be adopted to capture additional revenue by aligning generation behavior with regional price signals. Establishing long-term and short-term power trade agreements and pricing mechanism with India and Bangladesh would further stabilize export revenue and encourage private sector participation. In parallel, Nepal should develop the technical and institutional capacity to participate in real-time and day-ahead electricity markets, supported by modern forecasting and digital energy management tools.

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APPENDIX A: SUMMARY OF PROJECTS UNDER STUDY

Table A.1: Summary of Project pipeline and Monthly Energy by 2087/88

Status	Number	Capacity MW	Annual GWh	Dry GWh	Wet GWh	Shrawan	Bhadra	Aswin	Kartik	Mangsir	Poush	Magh	Falgun	Chaitra	Baisakh	Jestha	Ashad	Total GWh
Operation	177	3393	15578	4657	10921	1515	1897	1870	1580	1166	976	766	721	770	1137	1532	1647	15578
Construction Phase	105	4200	21894	6163	15731	2091	3023	3023	2472	1456	1123	889	850	853	1481	2232	2402	21894
Pre-construction	22	526	2893	870	2024	265	406	406	330	191	150	120	114	112	198	292	310	2893
Solar Operation	25	142	259	123	136	24	21	21	19	16	16	17	20	28	27	28	23	259
Solar Construction	12	84	154	73	81	14	13	12	12	9	9	10	12	16	16	17	14	154
Solar PPA LoI	61	944	1723	820	903	157	140	138	129	105	106	116	132	184	178	187	152	1723
Total	*402*	*9289*	*42501*	*12706*	*29795*	*4065*	*5500*	*5470*	*4542*	*2943*	*2380*	*1918*	*1849*	*1962*	*3036*	*4287*	*4547*	*42501*

APPENDIX B: HOURLY AVAILABILITY FACTOR

Table A.1: Fraction of Annual RoR Generation Available in every Slices of Time

	Shrawan	Bhadra	Aswin	Kartik	Mangsir	Poush	Magh	Falgun	Chaitra	Baisakh	Jestha	Ashad
H01	0.0047	0.0054	0.0056	0.0052	0.0038	0.0023	0.0019	0.0019	0.0021	0.0026	0.0030	0.0035
H02	0.0047	0.0054	0.0061	0.0052	0.0040	0.0023	0.0020	0.0019	0.0021	0.0026	0.0029	0.0034
H03	0.0047	0.0054	0.0055	0.0052	0.0038	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H04	0.0047	0.0054	0.0055	0.0052	0.0037	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H05	0.0046	0.0054	0.0055	0.0052	0.0037	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H06	0.0048	0.0054	0.0056	0.0052	0.0037	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H07	0.0048	0.0055	0.0056	0.0052	0.0037	0.0023	0.0020	0.0019	0.0021	0.0026	0.0029	0.0035
H08	0.0048	0.0055	0.0055	0.0051	0.0037	0.0024	0.0020	0.0019	0.0021	0.0026	0.0029	0.0034
H09	0.0048	0.0054	0.0055	0.0051	0.0037	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H10	0.0047	0.0054	0.0055	0.0051	0.0036	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H11	0.0048	0.0055	0.0055	0.0051	0.0036	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0034
H12	0.0048	0.0055	0.0054	0.0051	0.0036	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H13	0.0048	0.0055	0.0052	0.0051	0.0036	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0034
H14	0.0048	0.0055	0.0054	0.0051	0.0036	0.0023	0.0018	0.0019	0.0021	0.0026	0.0029	0.0034
H15	0.0048	0.0055	0.0054	0.0051	0.0036	0.0023	0.0019	0.0019	0.0021	0.0025	0.0029	0.0034
H16	0.0048	0.0054	0.0054	0.0051	0.0036	0.0023	0.0019	0.0019	0.0021	0.0026	0.0028	0.0034
H17	0.0047	0.0055	0.0054	0.0052	0.0036	0.0022	0.0019	0.0019	0.0021	0.0025	0.0028	0.0034
H18	0.0048	0.0055	0.0055	0.0052	0.0037	0.0024	0.0019	0.0019	0.0020	0.0024	0.0029	0.0035
H19	0.0046	0.0054	0.0054	0.0051	0.0037	0.0023	0.0019	0.0019	0.0021	0.0025	0.0029	0.0034
H20	0.0046	0.0055	0.0055	0.0052	0.0037	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0034
H21	0.0047	0.0055	0.0055	0.0052	0.0037	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H22	0.0046	0.0055	0.0054	0.0052	0.0037	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H23	0.0046	0.0054	0.0054	0.0052	0.0037	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0035
H24	0.0047	0.0055	0.0054	0.0052	0.0037	0.0023	0.0019	0.0019	0.0021	0.0026	0.0029	0.0034

Table A.2: Hourly Availability Factor of Solar

	Shrawan	Bhadra	Aswin	Kartik	Mangsir	Poush	Magh	Falgun	Chaitra	Baisakh	Jestha	Ashad
H01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01
H07	0.08	0.05	0.03	0.02	0.00	0.00	0.00	0.01	0.05	0.09	0.13	0.09
H08	0.24	0.18	0.18	0.16	0.08	0.05	0.05	0.11	0.25	0.28	0.32	0.24
H09	0.42	0.36	0.36	0.35	0.26	0.20	0.22	0.30	0.50	0.48	0.50	0.41
H10	0.62	0.54	0.56	0.56	0.43	0.37	0.42	0.51	0.73	0.68	0.68	0.53
H11	0.62	0.62	0.66	0.68	0.58	0.53	0.59	0.68	0.90	0.78	0.84	0.61
H12	0.65	0.63	0.62	0.72	0.64	0.63	0.68	0.74	0.93	0.83	0.86	0.63
H13	0.66	0.65	0.64	0.70	0.62	0.62	0.67	0.69	0.87	0.84	0.81	0.57
H14	0.63	0.58	0.65	0.59	0.55	0.56	0.60	0.58	0.80	0.77	0.73	0.57
H15	0.59	0.53	0.49	0.45	0.42	0.44	0.51	0.47	0.64	0.58	0.61	0.52
H16	0.41	0.39	0.35	0.26	0.21	0.27	0.33	0.36	0.48	0.43	0.47	0.40
H17	0.27	0.21	0.15	0.08	0.05	0.07	0.14	0.18	0.25	0.23	0.27	0.28
H18	0.14	0.05	0.02	0.00	0.00	0.00	0.01	0.03	0.08	0.08	0.12	0.14
H19	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03
H20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A.3: Fraction of Annual Demand occurring in every Slices of Time

	Shrawan	Bhadra	Aswin	Kartik	Mangsir	Poush	Magh	Falgun	Chaitra	Baisakh	Jestha	Ashad
H01	0.0036	0.0036	0.0033	0.0025	0.0024	0.0024	0.0024	0.0024	0.0026	0.0033	0.0036	0.0039
H02	0.0035	0.0035	0.0032	0.0025	0.0024	0.0024	0.0023	0.0024	0.0025	0.0032	0.0035	0.0036
H03	0.0035	0.0035	0.0032	0.0025	0.0023	0.0024	0.0023	0.0023	0.0025	0.0032	0.0034	0.0037
H04	0.0034	0.0034	0.0031	0.0025	0.0023	0.0024	0.0023	0.0023	0.0025	0.0031	0.0034	0.0036
H05	0.0034	0.0034	0.0032	0.0026	0.0026	0.0026	0.0024	0.0025	0.0026	0.0032	0.0034	0.0036
H06	0.0035	0.0034	0.0033	0.0029	0.0030	0.0030	0.0028	0.0029	0.0030	0.0033	0.0035	0.0034
H07	0.0037	0.0036	0.0035	0.0031	0.0032	0.0036	0.0034	0.0035	0.0033	0.0036	0.0037	0.0038
H08	0.0039	0.0038	0.0037	0.0033	0.0038	0.0040	0.0038	0.0037	0.0035	0.0037	0.0039	0.0039
H09	0.0038	0.0038	0.0037	0.0032	0.0036	0.0039	0.0037	0.0036	0.0034	0.0037	0.0039	0.0040
H10	0.0039	0.0039	0.0038	0.0032	0.0035	0.0038	0.0035	0.0035	0.0034	0.0037	0.0040	0.0041
H11	0.0040	0.0039	0.0037	0.0031	0.0033	0.0036	0.0034	0.0033	0.0033	0.0038	0.0041	0.0043
H12	0.0039	0.0039	0.0037	0.0030	0.0032	0.0035	0.0033	0.0032	0.0033	0.0039	0.0041	0.0043
H13	0.0040	0.0040	0.0037	0.0030	0.0031	0.0034	0.0032	0.0032	0.0033	0.0037	0.0041	0.0043
H14	0.0040	0.0040	0.0038	0.0030	0.0031	0.0034	0.0032	0.0031	0.0033	0.0039	0.0042	0.0043
H15	0.0039	0.0039	0.0038	0.0030	0.0032	0.0034	0.0032	0.0031	0.0033	0.0038	0.0041	0.0042
H16	0.0039	0.0038	0.0037	0.0031	0.0032	0.0034	0.0032	0.0032	0.0033	0.0038	0.0041	0.0042
H17	0.0039	0.0038	0.0037	0.0032	0.0034	0.0036	0.0033	0.0032	0.0033	0.0037	0.0040	0.0040
H18	0.0038	0.0038	0.0040	0.0041	0.0038	0.0044	0.0040	0.0035	0.0034	0.0037	0.0039	0.0039
H19	0.0041	0.0044	0.0045	0.0040	0.0040	0.0048	0.0042	0.0041	0.0040	0.0041	0.0041	0.0040
H20	0.0046	0.0045	0.0043	0.0037	0.0037	0.0040	0.0038	0.0037	0.0038	0.0042	0.0044	0.0051
H21	0.0043	0.0042	0.0040	0.0033	0.0032	0.0036	0.0034	0.0033	0.0035	0.0041	0.0043	0.0045
H22	0.0040	0.0040	0.0037	0.0029	0.0027	0.0030	0.0029	0.0028	0.0031	0.0038	0.0041	0.0042
H23	0.0038	0.0038	0.0034	0.0027	0.0025	0.0027	0.0026	0.0026	0.0028	0.0035	0.0038	0.0039
H24	0.0037	0.0037	0.0034	0.0026	0.0024	0.0026	0.0025	0.0025	0.0026	0.0035	0.0037	0.0039

APPENDIX C: OUTPUT AND RESULTS

A. Hourly Surplus/Deficit Table Based on:

Case 1: Demand following scheduling of PRoR and Storage

Table A.1: $E_{\text{Surplus}}[m,h] = E_{\text{RoR}}[m,h] + E_{\text{Solar}}[m,h] + E_{\text{PRoR}}[m,h] + E_{\text{Storage}}[m,h] - E_{\text{Demand}}[m,h]$

Months	H01	H02	H03	H04	H05	H06	H07	H08	H09	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24
Shrawan	2715	2810	2831	2855	2756	2864	2890	3037	3213	3318	3436	3471	3478	3400	3379	3191	2913	2901	2498	2249	2479	2496	2563	2678
Bhadra	4099	4111	4091	4101	4116	4094	4173	4405	4505	4762	4872	4857	4860	4799	4766	4562	4359	4294	3649	3675	3866	4078	3975	4079
Aswin	4325	4795	4322	4330	4304	4320	4326	4497	4689	4881	5032	4889	4790	4876	4746	4631	4343	4033	3597	3788	4036	4150	4180	4198
Kartik	4256	4263	4266	4255	4223	4164	4149	4566	4455	4723	4866	4926	4903	4767	4606	4380	4178	3704	3762	4056	4098	4181	4224	4229
Mangsir	1532	1742	1581	1454	1546	2025	1926	2734	3082	3391	2519	2667	2658	2578	2398	2122	1883	2616	2414	2748	1922	2159	1306	1380
Poush	342	371	387	368	218	-170	323	1280	1490	1806	900	1104	1083	204	58	689	320	1137	764	1208	335	-139	116	235
Magh	17	151	122	100	-2	-346	-26	1094	1324	1631	530	-13	29	-15	-135	-393	-344	1086	860	1187	-125	-456	-175	-76
Falgun	0	23	51	42	-88	-420	1263	1176	1514	410	370	166	143	33	-84	-240	-446	1477	988	1061	-761	-408	-143	-81
Chaitra	30	84	110	115	-11	-271	-539	1711	2077	2379	759	541	465	353	183	-42	-272	79	948	1181	1485	-347	-107	3
Baisakh	-135	-50	2	25	-23	-65	815	965	955	1166	2542	2594	1351	2492	971	1084	859	595	1323	1309	1418	609	-161	-261
Jestha	1306	1325	1342	1365	1369	1330	1378	1544	1729	1893	2047	2065	1977	1864	1728	1519	1326	1220	1067	968	1011	1114	1204	1249
Ashad	1638	1698	1731	1748	1754	1802	1813	1862	2096	2185	2144	2225	2051	2086	2065	1933	1859	1760	1574	1153	1422	1501	1602	1579

Case 2: Price based scheduling of PRoR and Storage

Table A.2: $E_{\text{Surplus}}[m,h] = E_{\text{RoR}}[m,h] + E_{\text{Solar}}[m,h] + E_{\text{PRoR}}[m,h] + E_{\text{Storage}}[m,h] - E_{\text{Demand}}[m,h]$

Months	H01	H02	H03	H04	H05	H06	H07	H08	H09	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24
Shrawan	3907	3781	2823	2807	2678	3852	4029	2701	2642	2582	2522	2535	2500	2184	2541	2533	2395	2547	3463	3034	3357	3506	3660	3810
Bhadra	4349	4401	4419	4446	4457	4440	4413	4405	4576	4762	4872	4857	3890	3109	4766	4562	4495	4294	3895	3921	4112	4324	4353	4508
Aswin	4682	5207	4755	4783	4703	4652	4531	4497	4689	4881	3380	4889	4790	3159	4746	4631	4385	4033	3843	4034	4282	4537	4696	4524
Kartik	5066	5098	5117	5100	4967	4719	4579	4566	3868	3655	3847	3931	3871	3650	3707	3665	4184	3950	4008	4302	4439	4731	4927	4991
Mangsir	2391	2282	1581	1454	2099	1860	1911	2980	3328	2252	2254	2329	1489	1412	2055	1909	3032	2862	2660	2748	1845	2151	2221	2260
Poush	96	125	141	122	-28	-416	-98	1526	1736	2052	896	662	637	-42	135	212	276	1137	764	1454	200	278	-130	-11
Magh	-229	-95	-124	-146	-248	-592	2	1340	1570	1877	121	-259	-217	-261	-381	-639	-941	1086	860	1187	-230	-110	-421	-322
Falgun	-246	-223	-195	-204	-334	-666	1509	1422	1760	161	-261	-80	-103	-213	-330	-486	-692	-897	988	1307	1648	226	-389	-327
Chaitra	180	84	110	-131	-11	-271	318	-452	-333	-30	195	295	219	107	-63	-288	-518	-856	1194	1427	1731	2062	2302	2413
Baisakh	2275	1489	1333	1165	1086	1090	900	315	-114	94	133	184	287	82	-116	-42	198	38	329	1555	1664	1921	2122	2149
Jestha	2405	2464	2504	2548	2305	2228	2159	835	651	691	769	793	713	583	646	627	643	1907	1680	1709	1790	1998	2200	2307
Ashad	2583	2583	2559	2606	1987	2748	2603	1494	1451	1364	1127	1187	971	966	1118	1173	1334	1408	2250	1604	2145	2338	2565	2555

B. Hourly Surplus/Deficit Table With Integration of Pump Storage Hydropower

Table A.3: $Surplus_{\text{PSH}}[m,h] = E_{\text{Solar}}[m,h] + E_{\text{RoR}}[m,h] + E_{\text{PRoR}}[m,h] + E_{\text{Storage}}[m,h] + E_{\text{pump,Gen}}[m,h] - E_{\text{Demand}}[m,h]$

Months	H01	H02	H03	H04	H05	H06	H07	H08	H09	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24
Shrawan	4696	4571	3612	3596	1750	4641	4819	1772	1713	1654	1593	1606	1572	1256	1613	1605	1466	1618	4252	3824	4147	4295	4449	4600
Bhadra	5138	5190	5208	3517	3529	5229	5202	5194	3647	3834	3944	3929	2961	2180	3837	3634	3567	3365	4685	4710	4901	5113	5142	5297
Aswin	5471	5207	4755	4783	4703	4652	5320	4497	3760	3953	2452	3961	3862	2230	3817	3703	3457	4823	4632	4824	5071	5327	5485	5313
Kartik	5066	5098	5117	5100	4967	4719	5368	5356	2940	2727	2918	3003	2943	2722	2779	2737	4184	4740	4797	5091	5228	5520	5716	4991
Mangsir	1463	1353	652	526	1170	961	2701	3770	4117	3041	3017	1401	561	484	1126	2699	3821	3651	3449	3537	2635	2940	1293	1332
Poush	-832	-803	-788	-806	-956	-1344	691	2315	2525	2841	1685	694	-88	-697	-380	212	1065	1926	1553	2244	990	278	-1059	-939
Magh	-1157	-1023	-1052	-1074	-1177	68	791	2129	2359	2667	910	530	-1001	-963	-978	-1026	-1105	1875	1649	1977	560	-1038	-1350	-1250
Falgun	-1174	-1151	-1124	-1133	-1263	123	2298	2211	2549	950	-1057	-945	-910	-892	-880	-907	-903	-107	1777	2096	2437	1015	135	-1256
Chaitra	478	84	110	-131	-11	-271	1107	-452	-918	-884	-734	-633	-709	-822	-812	-850	-810	-950	1983	2217	2520	2851	3091	3202
Baisakh	3064	2279	1673	1165	1086	1090	900	-12	-676	-702	-780	-744	-642	-819	-795	-546	-71	-56	329	2344	2454	2711	2911	2938
Jestha	3194	3253	3157	2548	2305	2228	2007	460	66	-105	-159	-135	-215	-272	-68	77	327	1767	1680	2498	2579	2787	2989	3096
Ashad	2583	2583	2559	2606	1987	2748	2603	1319	1069	930	809	794	767	735	867	1043	1212	1337	2250	1604	2145	3127	3354	3283

APPENDIX D: PSH OPERATIONAL ALGORITHM

Table A.1: Operational logic developed for PSH: Pump = 1: Generation = 0

	Shrawan	Bhadra	Aswin	Kartik	Mangsir	Poush	Magh	Falgun	Chaitra	Baisakh	Jestha	Ashad
H01	0	0	0	0	1	1	1	1	0	0	0	0
H02	0	0	0	0	1	1	1	1	0	0	0	0
H03	0	0	0	0	1	1	1	1	0	0	0	0
H04	0	1	0	0	1	1	1	1	0	0	0	0
H05	1	1	0	0	1	1	1	1	0	0	0	0
H06	0	0	0	0	1	1	0	0	0	0	1	0
H07	0	0	0	0	0	0	0	0	0	0	1	0
H08	1	0	0	0	0	0	0	0	0	1	1	1
H09	1	1	1	1	0	0	0	0	1	1	1	1
H10	1	1	1	1	0	0	0	0	1	1	1	1
H11	1	1	1	1	0	0	0	1	1	1	1	1
H12	1	1	1	1	1	0	0	1	1	1	1	1
H13	1	1	1	1	1	1	1	1	1	1	1	1
H14	1	1	1	1	1	1	1	1	1	1	1	1
H15	1	1	1	1	1	1	1	1	1	1	1	1
H16	1	1	1	1	0	0	1	1	1	1	1	1
H17	1	1	1	0	0	0	1	1	1	1	1	1
H18	1	1	0	0	0	0	0	0	1	1	1	1
H19	0	0	0	0	0	0	0	0	0	0	0	0
H20	0	0	0	0	0	0	0	0	0	0	0	0
H21	0	0	0	0	0	0	0	0	0	0	0	0
H22	0	0	0	0	0	0	1	0	0	0	0	0
H23	0	0	0	0	1	1	1	0	0	0	0	0
H24	0	0	0	0	1	1	1	1	0	0	0	0

Table A.2: PSH Generation optimized to high priced scheduling.

	Shrawan	Bhadra	Aswin	Kartik	Mangsir	Poush	Magh	Falgun	Chaitra	Baisakh	Jestha	Ashad
H01	789	789	789	0	0	0	0	0	298	789	789	0
H02	789	789	0	0	0	0	0	0	0	789	789	0
H03	789	789	0	0	0	0	0	0	0	341	652	0
H04	789	0	0	0	0	0	0	0	0	0	0	0
H05	0	0	0	0	0	0	0	0	0	0	0	0
H06	789	789	0	0	0	0	659	789	0	0	0	0
H07	789	789	789	789	789	789	789	789	789	0	0	0
H08	0	789	0	789	789	789	789	789	0	0	0	0
H09	0	0	0	0	789	789	789	789	0	0	0	0
H10	0	0	0	0	789	789	789	789	0	0	0	0
H11	0	0	0	0	763	789	789	0	0	0	0	0
H12	0	0	0	0	0	33	789	0	0	0	0	0
H13	0	0	0	0	0	0	0	0	0	0	0	0
H14	0	0	0	0	0	0	0	0	0	0	0	0
H15	0	0	0	0	0	0	0	0	0	0	0	0
H16	0	0	0	0	789	0	0	0	0	0	0	0
H17	0	0	0	0	789	789	0	0	0	0	0	0
H18	0	0	789	789	789	789	789	789	0	0	0	0
H19	789	789	789	789	789	789	789	789	789	0	0	0
H20	789	789	789	789	789	789	789	789	789	789	789	0
H21	789	789	789	789	789	789	789	789	789	789	789	0
H22	789	789	789	789	789	0	0	789	789	789	789	789
H23	789	789	789	789	0	0	0	523	789	789	789	789
H24	789	789	789	0	0	0	0	0	789	789	789	727

APPENDIX E: TRANSMISSION LINE CAPACITY ESTIMATION

Estimation of 400 kV Transmission Line Capacity

Step 1: Input Line Configurations and Information

- Rated Voltage (V): 400 kV (line-to-line)
- Number of Circuit: Double-circuit
- Conductor per Phase: Quad bundle (4 sub-conductors per phase)
- Conductor Type: ACSR Moose
- Conductor Cross-section: 500 sq.mm per sub-conductor

Step 2: Thermal Rating Assumptions

- Maximum Conductor Temperature (T_{max}): 75 °C
- Reference Ambient Temperature (Ta): 40°C
- Reference Wind Speed: 0.6 m/s
- Solar Irradiance: 1000 W/mš
- Emissivity (ε): 0.6, Solar Absorptivity (α): 0.8
- Temperature Coefficient of Aluminum (α_{20}): $0.004\,03\,\mathrm{K}^{-1}$

Step 3: Thermal Capacity Calculation
Conductor parameters from Manufacture Data
For ACSR "Moose" (~ 500 mm^2):

- DC resistance at 20°C: $R_{dc,20} = 0.058$ Ω/km per sub-conductor
- Single conductor ampacity (75°C, 40°C ambient): $I_{\text{single}} = 850$ A

The ampacity of a bundle is not simply 4 times that of a single conductor. A standard rule-of-thumb for a quad bundle is a multiplier of 2.9 to 3.4 on the single-conductor rating. Therefore, using bundle multiplication factor (K_{bundle}=3.2)
$I_{\text{therm.}}= I_{\text{single}} \times 3.2 = 850A \times 3.2 = 2720A$
Step 4: Calculate Thermal MVA Rating

For single circuit:

$$S_{\text{therm.,1ckt}} = \sqrt{3} \times V \times I_{\text{therm.}} = 1885 \text{ MVA}$$

For double circuit:

$$S_{\text{therm.,total}} = 2 \times S_{\text{therm.,1ckt}} = 3770 \text{ MVA}$$

Considering Power factor = 0.9

$$P_{\text{therm.,total}} = S \times 0.9 = 3393 \text{ MW} = approx.3400MW$$

Under N-1 Contingency: An N-1 contingency represents the loss of one circuit of the double-circuit transmission line without violating operational limits. In such a case transfer capacity of a transmission line is equivalent to single circuit.

Therefore, $\text{P}_{\text{Cap}=0.5\times}\text{P}_{,total}$ = approx. 1700 MW

APPENDIX F: LIST OF PROJECTS

I. List of Operational Projects

Table A.1: List of Operational Projects

S.N	Plant Name	Capacity MW	Lic No.	Promoter	Lic. date	CoD
1	Trisuli	24	1_gtd	Nepal Electricity Authority	2018/12/07	2023/12/07
2	Panauti	2.4	1_gtd	Nepal Electricity Authority	2018/12/07	2023/12/07
3	Fewa (Pokhara)	1.088		Nepal Electricity Authority	2022/12/07	2026/12/07
4	Sunkoshi	10.05	1_gtd	Nepal Electricity Authority	2024/12/07	2028/12/07
5	Tinau	1.024	1_gtd	Nepal Electricity Authority	2029/12/07	2034/12/07
6	Gandak	15	1_gtd	Nepal Electricity Authority	2034/12/07	2038/12/07
7	Kulekhani-I	60	1_gtd	Nepal Electricity Authority	2035/12/07	2039/12/07
8	Devighat	14.1	1_gtd	Nepal Electricity Authority	2037/12/07	2041/12/07
9	Seti	1.5	1_gtd	Nepal Electricity Authority	2038/12/07	2042/07/01
10	Kulekhani-II HP	32	1_gtd	Nepal Electricity Authority	2039/12/07	2043/12/07
11	Marsyangdi	69	1_gtd	Nepal Electricity Authority	2041/12/07	2046/06/15
12	Aandikhola	9.4	2_gtd	Butwal Power Company	2045/02/14	2048/02/18
13	Jhimruk	12	3_gtd	Butwal Power Company	2052/01/25	2051/05/01
14	Tatopani HP	2	1_gtd	Nepal Electricity Authority	2051/12/06	2051/12/30

Continued on next page

Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
15	Chatara	3.2		Nepal Electricity Authority	2052/04/01	2052/04/01
16	Khimti I	60	1	Himal Hydropower Co Ltd	2051/11/01	2056/12/17
17	Ilam Puwa Khola	6.2	2	Nepal Electricity Authority	2052/05/27	2056/12/22
18	Modi	14.8	3	Nepal Electricity Authority	2052/10/24	2057/08/24
19	U. Bhotekoshi	45	5	Bhotekoshi Power Company Pvt. Ltd	2050/02/05	2057/10/11
20	Kaligandaki 'A' HP	144	4	Nepal Electricity Authority	2053/07/21	2059/04/31
21	Indrawati 3	7.5	7	National Hydropower Company Limited	2054/11/14	2059/06/21
22	Chilime	22.1	6	Chilime Hydropower Company Ltd.	2054/04/26	2060/05/07
23	Piluwa	3.2	9	Arun Valley HP Dev. Ltd	2060/06/01	2060/06/01
24	Sunkoshi Small	2.6	12	Sanima Hydropower Company Limited	2059/06/22	2061/12/11
25	Chaku Khola Small	3.2	17	Laughing Buddha Power Nepal Pvt. Ltd.	2061/11/04	2062/03/01
26	Khudi	4	16	Khudi Hydro Power Company LTD	2061/11/13	2063/09/15
27	Thoppal Khola	1.65	19	Thoppal Khola Hydropower Co. Pvt. Ltd.	2063/03/25	2064/07/13
28	Middle M. HP	70.2	8	Nepal Electricity Authority	2057/03/12	2065/10/01

Continued on next page

Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
29	Ridi Khola	2.4	22	Ridi Hydro Power Development Company Limited	2064/02/17	2066/07/10
30	Mardi Khola	4.8	21	Gandaki Hydropower Development Co. Ltd.	2063/10/08	2066/10/08
31	Mai Khola Small	4.5	23	Himal Dolkha Hydropower Company Limited	2064/08/20	2067/11/01
32	Hewa Khola	4.5	25	Barun Hydropower	2065/01/22	2068/04/10
33	Bijaypur-1 Small	4.5	34	Bhagawati Hydropower Development Company Ltd.	2066/12/22	2069/05/05
34	Siuri	5	31	Nyadi Group (P) Ltd.	2066/05/30	2069/06/30
35	Lower Modi-1	10.2	29	United Modi Hydropower Pvt. Ltd.	2066/05/02	2069/08/09
36	Sipring Khola	10	27	Synergy Power Development P Ltd	2066/01/30	2069/10/03
37	Middle Chaku	1.8	44	Laughing Buddha Power Nepal Pvt. Ltd.	2067/12/07	2069/11/01
38	Tadikhola	5	54	Mountain Energy Nepal Ltd.	2068/08/06	2069/12/04
39	Charnawati khola	3.52	40	Nepal Hydro Developer Ltd.	2067/08/17	2070/02/24
40	Lower Chaku	1.8	26	Laughing Buddha Power Nepal Pvt. Ltd.	2065/05/09	2070/04/24
41	Ankhukhola Small	8.4	32	Ankhu Khola Hydropower Co. Ltd.	2066/08/26	2070/05/08
42	Bhairav kunda	3	30	Bhairab kunda khola Hydropower Co. Ltd.	2066/05/19	2071/02/22

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Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
43	Radhi Small	4.4	47	Radhi Bidyut Co. Ltd	2068/01/28	2071/02/31
44	Mailung Khola	5	13	Mailung Khola Hydropower Company Ltd	2060/12/03	2071/03/19
45	Upper Puwa-1	3	90	Joshi Hydropower Co. P. Ltd	2070/02/06	2071/10/01
46	Jiri Khola SHP	2.4	42	Bojini Company (P.) Ltd	2067/11/17	2071/11/01
47	Sanima Mai	22	37	Sanima Mai Hydropower Limited	2067/05/13	2071/11/14
48	Upper Hugdi	5	67	Ruru Jalbidyut Pariyojana Pvt. Ltd	2069/04/30	2071/12/09
49	Baramchi Khola	4.2	33	Unique Hydel Pvt Ltd	2066/10/26	2071/12/30
50	Nau gad khola	8.5	65	Api Power Company Ltd.	2069/03/31	2072/05/02
51	Mai Cascade	7	72	Sanima Mai Hydropower Limited	2069/07/15	2072/10/29
52	Chhandi Khola	2	103	Chhyandi Hydropower Co. Ltd	2070/05/24	2072/12/13
53	Upper Mai	12	36	Panchakanya Mai Hydropwer limited	2067/04/23	2073/03/09
54	Daram Khola-A	2.5	89	Sayapatri Hydropower Pvt. Ltd.	2070/02/02	2073/03/12
55	Jhyari Khola	2	63	Electrocom and Research Centre	2069/02/30	2073/04/01
56	Upper Marsyangdi A	50	60	Sinohydro-Sagarmatha Power Company Pvt Ltd	2068/12/17	2073/07/30

Continued on next page

Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
57	Khani Khola	2	85	Khani Khola Hydropower Company Ltd	2069/11/03	2073/08/09
58	Tungun - Thosne	4.36	84	Khani Khola Hydropower Company Ltd	2069/11/03	2073/08/09
59	Daraundi A	6	62	Kalika Power Company Limited	2069/02/16	2073/08/12
60	Upper Madi	25	35	Madi Power Pvt Ltd.	2067/01/27	2073/09/25
61	Hewa Khola A	14.9	58	Panchthar Power Company Pvt. Ltd.	2069/08/21	2074/01/10
62	Jogmai Khola	7.6	86	Sanvi Energy Pvt. Ltd.	2069/12/29	2074/01/18
63	Dwari Khola SHP	3.75	124	Bhugol Energy Development Company Pvt Ltd	2071/02/26	2074/01/23
64	Upper Mai -C	6.1	95	Panchakanya Mai Hydropwer limited	2070/03/21	2074/04/09
65	Sabha Khola HPP	4	81	Divyaswori Hydropower Ltd.	2069/10/04	2074/06/02
66	Puwa Khola-1	4	106	Puwa Khola - 1 Hydropower Pvt. Ltd	2070/06/21	2074/06/23
67	Phawa khola	5	39	Shiwani Hydropower Company	2067/06/19	2074/07/14
68	Thapa Khola	13.6	61	Mount Kailash Energy Co. Ltd.	2069/01/26	2074/08/22
69	Sardi Khola	4	94	Mandakini Hydropower Ltd.	2070/03/13	2074/08/23
70	Chake Khola	2.83	114	Garjyang Upatyaka Hydropower Ltd.	2070/11/21	2074/08/28

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Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
71	Midim Khola(Karapu)	3	68	Union Hydropower Limited	2069/05/06	2074/10/15
72	Chameliya Khola	30	20	Nepal Electricity Authority	2063/09/04	2074/10/27
73	Molun Khola	7	127	Molun Hydropower Co. Pvt. Ltd	2071/06/02	2074/12/12
74	Madkyu Khola	13	116	Sikles Hydropower Pvt.Ltd	2070/11/21	2074/12/19
75	Mai Sana Cascade	8	101	Himal Dolkha Hydropower Company Limited	2070/04/15	2074/12/26
76	Theule Khola	1.5	140	Barahi Hydropower Ltd	2072/03/28	2075/03/24
77	Super Mai	7.8	188	Supermai Hydropower Pvt.Ltd.	2073/11/30	2075/07/11
78	Rudi A	8.8	109	Bindhabasini Hydropower Dev Co. Ltd	2070/09/12	2075/12/05
79	Bagmati Nadi	22	125	Mandu Hydropower Pvt. Ltd.	2071/03/19	2075/12/19
80	Kapadigad	3.33	111	Salmanidevi Hydropower Pvt Ltd	2070/09/14	2076/02/25
81	Pikhuwa Khola	5	45	Eastern Hydropower Ltd	2067/12/07	2076/02/27
82	Lower Hewa	22.1	99	Mountain Hydro Power Nepal P Ltd.	2070/04/09	2076/04/21
83	U.Trishuli 3A	60	43	Nepal Electricity Authority	2067/11/15	2076/05/13
84	Upper Mardi	7	181	United Idimardi and R.B. Hydropower Pvt Ltd	2073/10/14	2076/06/20

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Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
85	Iwa Khola	9.9	139	Ridi Power Company Ltd	2072/03/28	2076/06/20
86	Kulekhani-III	14	24	Nepal Electricity Authority	2067/11/15	2076/07/01
87	Upper Naugad	8	177	Api Power Company Ltd.	2073/09/14	2076/07/13
88	Kabeli B - 1	25	98	Arun Kabeli Power Limited.	2070/03/28	2076/07/23
89	Padam Khola	4.8	207	Dolti Power Company P. Ltd	2074/06/29	2076/09/08
90	Ghalemdi Khola	5	110	Ghalemdi Hydro Limited	2070/09/14	2076/11/05
91	Rudi Khola-B	6.6	199	Bindhabasini Hydropower Dev Co. Ltd	2074/02/26	2076/11/05
92	Upper Khorunga	7.5	168	Terhathum Power Company Limited	2073/05/08	2076/11/17
93	Solu	23.5	117	Upper Solu Hydroelectric Company Ltd	2070/12/04	2076/12/10
94	Super Mai A	9.6	224	Sagarmatha Jalbidhyut Company P.Ltd.	2074/11/18	2077/02/32
95	Super Mai Khola Cascade HPP	3	250	Mai Khola Hydropower Ltd.	2075/11/05	2077/03/31
96	Rawa Khola	3	186	Rawa Energy Development Pvt Ltd	2073/11/26	2077/06/04
97	Namarjun Madi	12	78	Himalayan Hydropower Pvt.Ltd	2069/09/11	2077/06/13
98	Ghatte Khola	5	138	Manakamana Engineering HP	2072/03/24	2077/07/23

Continued on next page

Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
99	Bijaypur Khola 2 HPP	4.5	166	Civil Hydropower Company Limited	2073/04/25	2077/11/18
100	Taksar Pikhuwa	8	159	Taksar Pikhuwa Khola Hydropower Ltd.	2073/03/03	2078/01/01
101	Upper Chaku A	22.2	58	Shiva Sri Hydropower Pvt. Ltd	2068/11/12	2078/02/01
102	Mistri Khola	42	53	Mountain Energy Nepal Ltd.	2067/10/20	2078/03/03
103	Singati	25	150	Singati Hydro Energy Pvt. Ltd.	2072/09/30	2078/04/17
104	Richet Khola	5	214	Richet Jalbidhyut Company Pvt. Ltd.	2074/09/04	2078/04/28
105	Upper Tamakoshi	456	41	Upper Tamakoshi Hydropower Limited	2067/08/17	2078/05/04
106	Mai Beni	9.51	228	Samling Power company Pvt.Ltd	2075/01/06	2078/06/01
107	Lower Modi	20	38	Modi Energy Pvt . Ltd	2067/05/21	2078/06/14
108	Lower Jogmai Khola HPP	6.2	264	Asian Hydropower Ltd	2076/03/12	2078/07/15
109	Likhu-4	52.4	59	Green Ventures Co. Ltd	2068/11/28	2078/07/21
110	Upper Chhandi	4	233	Chhyandi Hydropower Co. Ltd	2075/02/09	2078/08/24
111	Lower Khare	11	64	Universal Power Company Limited	2069/03/19	2078/09/06
112	Sapsu Khola Small HP	7.151	211	Three Star Hydropower Company Limited	2074/08/29	2078/09/23
113	Likhu Khola A	51	148	Numbur Himalaya Hydropower Limited	2072/07/16	2078/10/25

Continued on next page

Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
114	Upper Syange	2.4	197	Upper Syange Hydropower Ltd.	2074/02/22	2078/11/15
115	Lower Tadi	4.996	88	Buddha Bhumi Nepal Hydropower Company Limited	2069/12/27	2078/12/10
116	Kabeli B-1 Cascade	9.94	277	Arun Valley HP Dev. Ltd	2076/07/26	2078/12/12
117	Upper Hewa	8.5	133	Upper Hewakhola Hydropower Company Limited	2072/01/15	2078/12/19
118	Suri Khola	7	134	Makar Jitumaya Suri Khola Hydropower Limited	2072/02/24	2079/01/18
119	Nyadi	30	83	Nyadi Hydropower Limited	2069/11/03	2079/01/27
120	Upper Khimti II	7	131	Himalaya Urja Bikash Company Limited	2071/12/13	2079/02/17
121	Uppallo Khimti	12	77	Himalaya Urja Bikash Company Limited	2069/09/03	2079/03/06
122	Dordi 1	12	82	Dordi Khola Jalvidyut Co. Limited	2069/10/12	2079/06/14
123	Dordi Khola	27	48	Himalayan Power Partner Limited	2068/03/23	2079/06/14
124	Chepe Khola	8.63	279	Aashutosh Energy Limited	2076/08/16	2079/06/16
125	Lower Likhu	28.1	154	Swet Ganga Hydropower and Construction Limited	2072/12/28	2079/07/19
126	Upper Balephi A	36	163	Balephi Hydropower Ltd.	2073/04/12	2079/08/06
127	Puwa 2	4.96	240	Peoples Power Limited	2075/06/23	2079/08/12

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Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
128	Upper Dordi A	25	121	Liberty Energy Company Limited	2071/01/15	2079/08/17
129	Middle Modi	18	93	Middle Modi Hydropower Limited	2070/03/07	2079/09/08
130	Mid Solu Khola	9.5	308	Mid Solu Hydropower Co. Ltd.	2077/04/22	2079/09/15
131	Kalanga	15.33	151	Kalanga Hydropower Limited	2072/12/14	2079/10/27
132	Upper Kalangad	38.46	152	Sanigad Hydro Limited	2072/12/14	2079/11/06
133	U.Piluwa Khola 2	4.72	149	Menchhiyam Hydropower Pvt. Ltd.	2072/09/03	2079/11/12
134	Solu Khola (Dudhkoshi)	86	126	Sahas Urja Limited	2071/06/02	2079/11/17
135	Upper Machha	4.55	283	Bikash Hydropower Co. Pvt. Ltd.	2076/09/29	2079/11/17
136	Makarigad	10	170	Makarigad Hydropower Pvt. Ltd.	2073/05/27	2079/11/27
137	Super Madi	44	192	Super Madi Hydropower Limited	2073/12/17	2079/12/27
138	Rukum gad	5	136	Rapti Hydro and General Construction Limited	2072/03/09	2079/12/28
139	Super Dordi Kha	54	115	Peoples Hydropower Co. Ltd.	2070/11/21	2080/02/08
140	Upper Solu	19.8	169	Beni Hydropower Ltd.	2073/05/16	2080/03/01
141	Maya Khola	14.9	123	Maya Khola Hydropower Co. Ltd.	2071/02/26	2080/03/22
142	Likhu 2	55	146	Global Hydropower Associate Limited	2072/06/22	2080/04/15

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Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
143	Down Piluwa	10.3	113	RIver Falls Power Limited	2070/11/04	2080/04/25
144	Upper Chameliya	40	273	Api Power Company Ltd.	2076/06/12	2080/04/28
145	Upper Sanigad	10.7	153	Bungal Hydro Limited	2072/12/14	2080/05/02
146	Ghar Khola	14	137	Myagdi Hydropower Limited	2072/03/11	2080/05/08
147	Upper Sanjen	14.8	69	Sanjen Jalvidyut Company Limited	2069/05/07	2080/06/21
148	Gelun Khola HPP	3.2	91	Gelun Khola Hydropower Company Pvt Ltd	2070/02/06	2080/08/15
149	Upper Suri	7	268	Makar Jitumaya Suri Khola Hydropower Limited	2076/04/15	2080/08/21
150	Super Chepe	9.05	341	Ridge Line Energy Limited	2078/02/07	2080/10/08
151	Upper Mailun	14.3	79	Upper Mailung Khola Hydropower Limited,	2069/09/20	2080/10/28
152	Yambaling	7.271	172	Yambaling Hydropower Ltd.	2073/06/09	2080/11/08
153	Likhu 1	77	145	Pan Himalaya Energy Limited	2072/06/22	2080/12/19
154	Nilgiri Khola-II cascade	71	241	Nilgirikhola Hydropower Company Limited	2075/07/07	2080/12/24
155	Upper Ingwa Khola	9.7	329	Ingwa Hydopower Ltd.	2077/07/28	2080/12/28
156	Upper Midim	7.5	272	Bhujung Hydropower Ltd.	2076/05/26	2081/01/06

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Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
157	Upper Phawa	5.8	238	Unitech Hydropower Company Ltd.	2075/05/19	2081/01/08
158	Middle Tamor	73	198	Sanima Middle Tamor Hydropower Ltd	2074/02/22	2081/01/23
159	Upper Chirkhuwa	4.7	185	Chirkhuwa Hydropower Company Pvt td	2073/11/11	2081/02/20
160	Seti Khola HPP	3.5	205	Parbat Paiyu Khola Hydropower Company	2074/05/26	2081/03/07
161	Chepe A HEP	7	297	Champawati Hydro Power P.Ltd	2077/02/15	2081/03/25
162	Dudhkunda Khola	12	280	Mount Everest Power Development P.Ltd.	2076/08/18	2081/04/16
163	Nilgiri Khola	38	202	Nilgirikhola Hydropower Company Limited	2074/04/31	2081/04/21
164	Upper Richet	2	258	Upper Richet Hydropower Pvt. Ltd.	2076/02/07	2081/05/27
165	Seti Nadi	25	304	Vision Lumbini Urja Company Limited.	2077/03/15	2081/07/27
166	Sanjen	42.5	55	Sanjen Jalvidyut Company Limited	2068/08/12	2081/09/01
167	Super Kabeli Khola A	13.5	347	Snow River Ltd	2078/07/12	2081/09/05
168	Rasuwagadhi	111	75	Rasuwagadhi Hydropower Company Ltd.	2069/08/21	2081/09/16
169	Lankhuwa	5	200	Sabhapokhari Hydropower Ltd.	2074/03/28	2081/10/24
170	Sanjen Khola	78	160	Salasungi Power Ltd.	2073/03/09	2081/10/29

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Table A.1 – continued

S.N	Plant Name	Capacity (MW)	Lic.No.	Promoter	Licensed Date	CoD
171	Bhim Khola	4.96	284	Shikhar Power Development Ltd.	2076/09/29	2081/11/25
172	Super Kabeli	12	348	Hilton Hydro Energy Ltd.	2078/07/12	2081/12/02
173	Super Hewa	6	254	Super Hewa Power Company Ltd.	2075/12/26	2082/01/01
174	Upper Lohore	4	246	Upper Lohore Khola Hydropower Company Ltd.	2075/09/16	2082/01/04
175	Karuwa Seti	32	305	Jhyamolongma Hydropower Development Company Ltd.	2077/03/15	2082/01/19
176	Jogmai Cascade	5.2	285	Sanvi Energy Pvt. Ltd.	2076/10/01	2082/03/11
177	Rele Khola	6	221	Hym Consult Ltd.	2074/10/28	2082/03/23

II. List of Under-Construction Hydropower Projects

Table A.2: List of Under-Construction Projects and Physical Progress as of FY 2081/82

S.No.	Project Name	Capacity MW	Lic. No.	PPA Status	Progress	Expected COD
1	Khani Khola - 1	40	46	2067.06.24 & 2074.02.20	92.00%	2082
2	Rahuganga	40	49	2075.12.18	81.00%	2083
3	Tadi Khola	5	51	2067.01.09	28.00%	2086
4	Upper Mailung -A	6.42	56	2067.03.25 & 2071.11.19	80.00%	2083
5	Kabeli-A	37.6	70	2072.06.07	72.00%	2084
6	Junbeshi	5.2	80	2069.12.29	70.00%	2084

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Table A.2 – continued

S.N.	Project	Capacity (MW)	Lic. No.	PPA Status	Progress	Expected FY COD
7	Khorunga Khola	4.8	87	2069.08.26	100.00%	2082
8	Khani Khola	30	92	2069.03.25	92.50%	2082
9	Upper Trishuli 3B	37	104	2074.05.06	73.80%	2084
10	Upper Parajuli Khola 1	2.15	102	2069.08.28	85.00%	2083
11	Lohore Khola	4.2	105	2069.09.08	0.00%	2087
12	Salankhu Khola	2.5	107	2069.06.14	35.00%	2087
13	Madhya Bhotekoshi	102	108	2068.07.28	99.00%	2082
14	Rawa Khola HPP	6.5	112	2069.09.26	0.00%	2087
15	Lower Solu	82	118	2070.07.15	97.00%	2082
16	Upper Myagdi	37	119	2071.12.17	5.00%	2086
17	Sabha Khola A	10.4	128	2071.12.02 &2075.02.18	0.00%	2086
18	Darbang Myagdi Khola	25	130	2073.04.28	17.00%	2086
19	Balephi A	22.14	132	2069.07.14	40.00%	2085
20	Langtang Khola Small	20	142	2072.09.29 & 2074.07.16	80.00%	2083
21	Siddhi Khola	10	143	2074.05.29	51.00%	2084
22	Upper Tadi	11	144	2068.12.03	87.00%	2083
23	Chulepu Khola	8.52	155	12/23/2071	25.00%	2086
24	Chauri Khola	5	156	2072.06.14 & 2076.01.06	10.00%	2086
25	Tanahu Seti HEP	140	157	2075.03.15	67.00%	2084
26	Phalakhu Khola HPP	5	161	8/24/2071	30.00%	2085
27	Phalakhu Khola HPP	14.7	162	2069.12.06	20.00%	2086
28	Liping Khola	16.26	164	2073.02.28	85.20%	2083
29	Lower Khorunga	5.5	165	8/24/2074	20.00%	2086
30	Sano Milti Khola SHP	3	173	2073.01.13	32.50%	2085

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Table A.2 – continued

S.N.	Project	Capacity (MW)	Lic. No.	PPA Status	Progress	Expected FY COD
31	Rahughat Mangale	37	175	2075.03.29	88.00%	2083
32	Khimti II	48.8	179	2072.06.14	70.00%	2084
33	Upper Lapche Khola	42	182	4/20/2073	40.00%	2085
34	Daram Khola HEP	9.6	183	2073.10.09 & 2075.06.16	72.00%	2084
35	Ankhu Khola	42.9	184	2073.01.30	31.00%	2085
36	Sabha Khola-B HPP	15.1	187	2074.03.26	36.00%	2085
37	Middle Tara Khola SHP	1.7	190	2079-02-31	70.00%	2084
38	Upper Chauri Khola	6	194	2074.07.27	85.00%	2083
39	Lower Chirkhuwa	4.06	196	2074.01.20	0.00%	2087
40	Mewa Khola	50	201	2074.02.21	87.77%	2083
41	Buku-Kapati	5	203	2074.10.11	86.83%	2083
42	Super Nyadi	40.27	204	2074.02.19	69.33%	2085
43	Upper Trishuli-1	216	209	2074.10.14	78.00%	2084
44	Lapche Khola	160	212	2074.07.29	15.00%	2086
45	Kasuwa Khola HPP	45	213	2075.08.13	15.00%	2086
46	Saptang Khola HPP	2.5	215	2074.04.08	25.00%	2085
47	Buku Khola	6	216	2070.02.02	5.00%	2087
48	Super Trishuli	100	218	2075-07-11	5.00%	2087
49	Lower Irkhuwa khola	14.15	219	2075.11.23	0.00%	2087
50	Irkhuwa Khola-B HPP	15.524	222	2075.02.14	23.83%	2086
51	Rasuwa Bhotekoshi	120	223	9/7/2074	25.00%	2086
52	Upper Gaddi Gad	1.55	225	2075.04.03	99.00%	2082
53	Upper Khudi	26	232	2076.01.11	60.00%	2084
54	Upper Tamor	285	234	2079.07.17	20.00%	2087
55	Hewa A Small HEP	9.4	235	2075.10.17	60.00%	2084
56	Super Aankhu Khola	25.4	239	2074.09.15	15.00%	2086

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Table A.2 – continued

S.N.	Project	Capacity (MW)	Lic. No.	PPA Status	Progress	Expected FY COD
57	Nyadi-Phidi HPP	21.4	252	2075.02.24	14.00%	2086
58	Upper Rahughat	48.5	253	2075.03.29	40.00%	2085
59	Likhu Khola HPP	30	263	2075.05.26	25.00%	2085
60	Sagu Khola HEP	20	278	2075.04.10	75.00%	2084
61	Upper Ankhu Khola	38	280	2075.06.14	8.13%	2087
62	Sangu Khola HPP	5	286	2075.08.09	68.00%	2084
63	Middle Mewa HPP	73.5	289	2075.05.24	70.00%	2083
64	Nupche Likhu HEP	57.5	290	2074.11.28	87.00%	2083
65	Upper Myagdi-I HEP	53.5	291	2080-03-11	11.47%	2086
66	Sagu khola 1 HPP	5.5	292	2075.04.10	79.00%	2083
67	Phedi Khola (Thum-lung) Small	4.3	293	2075.06.21	10.00%	2086
68	Thulo Khola	21.3	294	2075.02.17	85.00%	2083
69	Upper Irkhuwa HPP	14.5	295	2075.04.01	61.25%	2084
70	Isuwa Khola	97.2	296	2075.06.26	0.00%	2087
71	Madame Khola HPP	24	299	2075.04.15	70.55%	2084
72	Lower Balephi	20	300	2077.03.30	0.00%	2087
73	Madya Super Daraundi HPP	10	301	2075.11.23	21.00%	2086
74	Rauje Khola HPP	18.6	302	2075.12.4	10.00%	2087
75	Upper Piluwa 3 HPP	4.95	306	2075.12.12	85.00%	2083
76	Hidi Khola HEP	6.82	307	2075.10.04	72.00%	2083
77	Landruk Modi HEP	86.59	313	2075.04.13	5.00%	2087
78	Sunigad HEP	11.05	314	2074.11.30	44.00%	2085
79	Dudhkoshi-2 Jaleswar HPP	70	316	8/6/2078	16.00%	2087
80	Lower Mid Rawa Khola	4	319	2080-01-28	15.00%	2086

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Table A.2 – continued

S.N.	Project	Capacity (MW)	Lic. No.	PPA Status	Progress	Expected FY COD
81	Midim 1 HEP	13.424	323	10/7/2075	21.00%	2086
82	Upper Bhurundi Khola SHP	3.75	327	2075.12.10	0.00%	2087
83	Nyasim HEP	35	328	2075.05.26	15.00%	2086
84	Setikhola HEP	22	334	2074.11.11	22.00%	2086
85	Mewa khola HEP	23	336	2075.10.04	28.88%	2085
86	Dudhpokhari Chepe HEP	8.836	338	10/15/2075	20.00%	2085
87	Upper Balephi	46	345	2080-08-05	10.00%	2087
88	Ilep Tatopani Khola HEP	25	346	2075.03.25	21.00%	2086
89	Kabeli-3 HEP	21.93	350	2075.10.03	89.62%	2083
90	Bhalaudi Khola HEP	2.645	351	2076.01.06	12.00%	2085
91	Isuwa Khola PRoR Cascade HEP	40.1	356	2077.09.27	20.00%	2086
92	Mathillo Kabeli HEP	28.1	359	4/2/2080	26.61%	2085
93	Middle Hongu Khola B HEP	22.9	361	2074.12.08	0.00%	2087
94	Upper Deumai Khola Small HEP	8.3	363	2079-08-13	15.00%	2086
95	Tamor Khola-5 HEP	37.5	365	2075.12.04	0.00%	2087
96	Mathillo Thulo Khola A HEP	22.5	371	2075.04.24	84.18.%	2083
97	Madhya Hongu Khola - A HPP	22	374	2075.05.14	0.00%	2087
98	Middle Trishuli Ganga nadi	15.625	379	9/3/2075	20.00%	2086
99	Syarpu HEP	3.3	385	4/11/2078	80.00%	2083
100	Bhotekoshi 1 HEP	44	388	2075-03-15	61.64%	2084

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Table A.2 – continued

S.N.	Project	Capacity (MW)	Lic. No.	PPA Status	Progress	Expected FY COD
101	Luja Khola HEP	24.8	391	2075-10-16	25.00%	2085
102	Tallo Indrawati HEP	4.5	401	11/25/2079	38.00%	2084
103	Super Machha Khola HEP	4.6	414	2080-03-21	20.00%	2085
104	Arun 3	900	001/74-75		75.00%	2085
105	Sabha Khola C HEP (Cascade)	6.3	419	2075-12-10	10.00%	2086

APPENDIX G: PLAGIARISM TEST REPORT

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