Pumped Storage Hydropower in India: Drive, Initiatives, Market Growth and Challenges

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Department of Hydro and Renewable Energy
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Disclaimer

The data, information, and charts used in this study are based on the data obtained from various sources and are acknowledged thankfully. Every care has been taken to ensure that the data is correct, consistent, and complete as far as possible and duly referred.

The constraints of time and resources available to this nature of the assignment, however, do not preclude the possibility of errors, omissions etc. in the data and consequently in report preparation.

Photograph on the cover is of Pinnapuram off stream closed loop PSP courtesy Greenko Group.

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अध्यक्ष तथा पदेन सचिव भारत सरकार
GHANSHYAM PRASAD
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FOREWORD

As the primary body entrusted with providing technical support and advice to all stakeholders in the power sector and advising the central and state levels on power policy matters, the Central Electricity Authority (CEA) is at the forefront of India's ongoing energy transition. Grid flexibility is essential to ensure that this transition does not compromise the reliability of the power grid and the quality of power delivered.

2. With deepening electrification and increasing dependence on electricity across various sectors of our society and economy, the reliability and resilience of the power grid are becoming ever more critical. In this context, Pumped Storage Hydropower (PSP) emerges as a vital grid-scale energy storage solution for India. PSP offers several advantages, including a high degree of indigenization and decades of operator experience, particularly in fixed-speed technologies.

3. CEA is actively working to accelerate the development of PSP projects across the country, while ensuring compliance with all relevant standards and policies. In 2024–25 alone, the CEA concurred with six PSP Detailed Project Reports (DPRs) totalling approximately 7.5 GW and about over 60 GW is under different stage of preparation and development—marking a significant milestone in India's commitment to building advanced, long-term energy storage capacity.

4. It is, therefore, a matter of great satisfaction to see academia—particularly IIT Roorkee—taking a keen interest in supporting PSP development. This report contributes meaningfully to our collective efforts by offering an international perspective on PSP technology. It provides stakeholders with a comprehensive reference that captures global experiences, including supportive policies, regulations, and business models. I am pleased to note that the report extensively references CEA's existing work on PSP in India. This approach avoids duplication and instead builds upon established knowledge, offering fresh insights into the challenges facing the sector and potential solutions.

5. I commend Prof. Arun Kumar, the lead author, and his team members from Department of Hydro Power, Indian Institute of Technology Roorkee for putting together this excellent document. I am confident that it will serve as a valuable resource for all stakeholders working toward the full realization of PSP's potential in India.

(Ghanshyam Prasad)

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Foreword

IIT Roorkee is deeply committed to supporting the nation's goal of achieving clean, carbon-neutral energy systems by 2070. Through cutting-edge research and world-class teaching, on par with the best global institutions, we are contributing meaningfully to the ongoing energy transition. However, to expand our impact, collaboration among industry, academia, and government is essential.

This report is an excellent example of such collaboration. The work carried out by IIT Roorkee has been rigorously reviewed by experts from all three sectors, and their feedback has shaped a document that is both academically robust and practically relevant for industry adoption.

The Department of Hydro and Renewable Energy (HRED) has been IIT Roorkee's flagship department for hydropower research and education for over four decades. This legacy is reflected in the depth of analysis and multidimensional recommendations presented in this report, particularly regarding the advancement of Pumped Storage Hydropower (PSP) in India.

It is my sincere hope that this report serves as a catalyst for even deeper collaboration among academia, industry, and government—especially through HRED and other departments of IIT Roorkee—so that we may contribute to developing the technologies and skilled workforce necessary to position India as a global leader in clean energy.

I thank Prof. Arun Kumar for leading this effort, and I extend my appreciation to the entire team from Department of Hydro Power, Indian Institute of Technology Roorkee for putting together this excellent document for preparing such a detailed and well-researched report.

(K K Pant)

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ACMEUTP	ACME Urja Two Private Limited
AGEL	Adani Green Energy Limited
AGEL	Adani Green Energy Ltd
AGEVI	Astha Green Energy Ventures India Pvt. Ltd.
APGENCO	Andhra Pradesh Power Gen Corp Ltd.
APSPCL	Andhra Pr Solar Power Corpo. Pvt Ltd.
AR&I	Aurobindo Realty & Infrastructure
AR&IPL	Aurobindo Realty & Infrastructure Pvt. Ltd
CEA	Central Electricity Authority
CAPEX	Capital cost
CERC	Central Electricity Regulatory Commission
CERC	Central Electricity Regulatory Commission
CPSU	Central Public Sector Undertakings
CSS	Cross Subsidy Surcharge
CTU	Central Transmission Utility
DPR	Detailed Project Report
EAC	Expert appraisal committee
EC	Environmental clearance
ED	Electricity Duty
EoDB	Ease of Doing Business
EPC	Engineering, Procurement and Construction
ESO	Energy Storage Obligation
ESS	Energy storage system
GPCL	Gujarat Power Corporation Limited
GSECL	Gujarat State Electricity Corp. Ltd
GSEPL	Greenko Solar Energy Pvt. Ltd
GW	Gega Watt
HML	Harmonized Master List HML
HP-DAM	High Price Day Ahead Market
HRT	Head race tunnel
I-DAM	Integrated Day Ahead Market
IREDA	Indian Renewable Energy Development Agency Limited
ISP	Indosol Solar Power
ISPPL	Indosol Solar Power Pvt. Ltd
IST	Inter-State Transmission
ISTS	Inter-State Transmission System
JSWEL	JSW Energy Ltd.
JSWEPSPTL	JSW Energy PSP Two Limited
KPCL	Karnataka Power Corp Ltd.
KREDL	Karnataka Renewable Energy Dev Ltd
LDES	Large Duration Energy Storage
LIS	Lift Irrigation Scheme
MAHAGENCO	Maharashtra State Power Generation Co.Ltd.
MERC	Maharashtra Electricity Regulatory Commission
MoEF&CC	Ministry of Environment, Forest and Climate Change
MW	Mega Watt
MWRD	Maharashtra Water Resources Department
NEP	National Electricity Plan
NHDC	Narmada Hydroelectric Dev Corp Ltd.
NHPC	NHPC Ltd.
NLDC	National Load Dispatch Center
NREDCAP	New & Renewable Energy Development Corporation of Andhra Pradesh Ltd.
O&M	Operation and maintenance
OHPCL	Odisha Hydro Power Corporation Ltd
PFC	Power Finance Corporation LTd
POSOCO	Power System Operation Corporation
PPA	Power purchase agreement
PRAS	Primary Reserve Ancillary Service
PSP	Pumped Storage Hydropower
RE	Renewable Energy
REC	Renewable energy certificates
RLDC	Regional Load Dispatch Center
RPC	Regional Power Committees
RPO	Renewable Purchase Obligation
RTC Power	Round the clock power
S & I	Survey and Investigation
SERC	State Electricity Regulatory Commissions
SLDC	State Load Dispatch Center
SPSU	State Public Sector Undertakings
SRAS	Secondary Reserve Ancillary Service
SSE	Shirdi Sai Electrical
SSNNL	Sardar Sarovar Narmada Nigam Limited
STU	State Transmission Utilities
TANGEDCO	Tamil Nadu Gen and Dist Corp. Ltd
TBCB	Tariff Based Competitive Bidding
THDC	Tehri Hydro Development Corporation
TNERC	Tamil Nadu Electricity Regulatory Commission
ToR	Terms of Reference
TPCL	Tata Power Company Limited
TRAS	Tertiary Reserve Ancillary Service
TSERC	Telangana State Electricity Regulatory Commission
TSGENCO	Telangana State Power Generation Corporation Ltd
VRES	Variable renewable energy sources
WAPCOS	Water and Power Consultancy Services (India)
WBERC	West Bengal Electricity Regu Commission
WBSEDCL	West Bengal State Electricity Distribution Comp. Ltd.
WRD	Water Resources Department

PREFACE

Global power generation is undergoing a definitive transition toward renewable energy sources, accompanied by a strategic mandate to diminish reliance on conventional fossil fuels. Within this framework, Pumped Storage Hydropower (PSP) has emerged as a reliable energy storage solution essential for balancing the grid. Currently, PSP constitutes over 90% of the world's long-duration energy storage capacity, representing approximately 200 GW of installed infrastructure. While roughly 400 PSP facilities are presently operational, an additional 214 GW of capacity is currently in various phases of development globally.

India revealed its five-point climate action plan, or *Panchamrit*, at the United Nations Climate Change Conference in Glasgow, Scotland (CoP26) in 2021. These primarily focus on achieving 500 GW of renewable energy capacity by 2030, reduction in carbon emissions by 1 billion tonnes from current (CoP26) levels by 2030, reducing the carbon intensity by 45% by 2030 and reaching the goal of net zero emissions by 2070. Thus, India intends to use wind and solar energy to meet above mentioned targets. In order to integrate large amounts of renewable energy into India's power system while maintaining grid stability and electricity quality, energy storage options has become increasingly crucial. Therefore, Government of India is now promoting PSP with its all-supportive measures through new policies, regulations, guidelines and national framework for smooth PSP development.

The identified PSP potential of India is around 224 GW comprising off-river and on-river PSP potential of about 165 GW and 59 GW, respectively. According to recent data from CEA (October 2025), there are 65 on-river PSP sites with a combined capacity of around 59 GW at different stages of development or in operation. Additionally, 132 off-river PSP sites with a combined capacity of about 165 GW are at various stages of development. Of these sites, 6,686 MW of PSPs at 10 PSP sites are operational, 11 PSP sites with a potential of 12,110 MW are under construction, and 5 PSP sites with capacity of 6,580 MW are concurred for execution.

The primary objective of the present study is to present a comprehensive review of the state of PSP development in Indian and globally, including technology, policies and regulations, and business models of PSPs. Recommendations for accelerating PSP development in India are also presented. In order to gain experience on current PSP development in India, data and information was obtained from official websites of Ministry of Power, Central Electricity Agency (CEA), published and unpublished reports, personal communications with Govt. officials of central and state agencies and other stakeholders. We thankfully acknowledge the support received from the above-mentioned sources/individuals.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Since many economies have set ambitious decarbonization goals and committed to clean energy generation, global electricity production is steadily shifting from traditional fossil fuels toward renewable sources. During this transition, Pumped Storage Hydropower (PSP) schemes are emerging as a reliable and adaptable technology for maintaining an efficient energy mix and grid stability. According to the International Hydropower Association (2025), PSP is the largest form of renewable energy storage, with nearly 200 GW of installed capacity. It currently provides more than 90% of all long-duration energy storage worldwide, with over 400 projects in operation [1].

It is well-established that PSP has significant potential to shape and support a sustainable energy mix. PSP systems can effectively support the power grid and be integrated with renewable energy sources to manage their inherent intermittency (Kumcu and Wahidi, 2019). This is particularly valuable for solar and wind power plants. Consequently, during periods of peak demand, PSP serves as a crucial resource to compensate for power shortages and supply irregularities caused by the variable nature of renewable energy systems. This unique feature of PSP maximizes the utilization of renewables and facilitates the creation of a cleaner, more sustainable energy infrastructure. As a result, PSP offers a clean alternative to fossil-fuel-based storage methods, characterized by zero emissions during generation and minimal ecological impact (Das, 2023).

1.2 SCOPE OF THE STUDY

The current study was conducted at the Department of Hydro and Renewable Energy (HRED), Indian Institute of Technology (IIT) Roorkee. It focuses primarily on promoting Pumped Storage Hydropower (PSP) as a vital technology for energy storage and grid stability in India. By conducting a comprehensive examination of international markets, global business models, and various configurations—alongside an analysis of ongoing PSP activities across several Indian states—this study aims to facilitate and accelerate PSP deployment throughout the country.

1.2.1 International market study on PSP development

Through a comprehensive literature review, this study evaluates global PSP markets to obtain valuable information on international operational strategies and the measures planned to increase PSP deployment. Generally, the evaluation includes:

1. **Studying** the core goals of various PSP markets;
2. **Understanding** the institutional backgrounds governing these markets;
3. **Identifying** the range of grid services that PSPs offer;

[1] https://www.hydropower.org/publications/enabling-new-pumped-storage-hydropower

4. **Evaluating** market evolution, specifically how PSPs facilitate the integration of renewable energy (RE) through traditional and emerging grid services; and
5. **Analyzing** the favorable regulatory and policy environments that support PSP development across different nations.

In addition, the study evaluates prevailing business models and pricing mechanisms, specifically addressing incentives that encourage wider adoption. It examines compensation structures under current tariff regimes for both pumping and discharging cycles, as well as pricing mechanisms tailored to specific use cases, such as energy arbitrage, peak load shaving, ancillary services, round-the-clock support, and renewable energy smoothing. Finally, the research assesses the benefits and drawbacks of various PSP strategies regarding funding, revenue generation, operational effectiveness, and environmental impact.

1.2.2 Selecting case studies by evaluating successful global PSP initiatives

By analyzing successful global case studies, this study evaluates the operational, design, and technical requirements of PSP projects. Furthermore, it identifies the key elements contributing to their success, including business and operating models, financing structures, regulatory frameworks, grid integration strategies, and diverse configurations—such as off-river, on-river, sea-based reservoirs, gravity-based systems, and the utilization of abandoned mines (both open-pit and underground), as well as the retrofitting of existing hydropower plants. The research also investigates the challenges these utilities encountered and the mitigation strategies adopted to overcome them.

Consequently, the most significant lessons and best practices from international markets are synthesized to guide PSP development within the Indian setting. This effort entails identifying business models that successfully optimize profits and attract private capital, while assessing their adaptability to the specificities of the Indian market. Ultimately, this study offers evidence-based suggestions to expand PSP deployment in India, recommending configurations—such as sea-based or mine-based layouts—and operating models that align with the unique characteristics and regulatory framework of the Indian energy sector.

1.2.3 Evaluation of current PSP initiatives in Indian

To understand PSP development in India, a thorough analysis was conducted on projects that are currently underway as well as those planned across the country. Additionally, projects under development were assessed to identify financial limitations, regulatory impediments, and other obstacles preventing smooth execution. Assessing the progress, challenges, and lessons learned from these projects is essential for developing policies that effectively promote PSP development in India. Furthermore, the study examines how equipment manufacturers, government organizations, private companies, and other stakeholders have contributed to the growth of the PSP sector in India.

1.3 METHODOLOGY

For the present study, a systematic literature review was undertaken to establish a comprehensive background on PSP technology, including its design, planning strategies, and development. Various digital platforms were searched to gather online reports, databases, expert opinions, technological innovations, market trends, government policies, and incentives. The primary organizations and websites consulted for pertinent data include:

- **Governing of India Authorities:** Central Electricity Authority (CEA), Ministry of Power (MoP), and Ministry of New and Renewable Energy (MNRE).
- **International Bodies:** International Forum on Pumped Storage Hydropower (IFPSH), International Hydropower Association (IHA), International Energy Agency (IEA), and The Asia Foundation.
- **Foreign National Associations:** National Hydropower Association (NHA), Federation of Electric Power Companies of Japan (FEPC), and German Energy Storage Systems Association (BVES/GESSA).
- **Foreign Government Portals & Databases:** U.S. Energy Information Administration (EIA), China Energy Portal, and Global Earth System Data Bank (GESDB).

Furthermore, the study involved a review of pertinent publications and recent reports—both published and unpublished—sourced from various archives, libraries, and PSP specialists. The majority of these research papers were sourced from reputable international journals published after 2020, focusing on market trends, case studies, technological advancements, economic viability, and renewable energy integration.

Online research served as the primary method for identifying global best practices through case studies. Contact information for responsible agencies, owners, operators, and contractors was retrieved from available directories to facilitate direct communication for deeper insights. Additionally, the official websites of major electromechanical equipment manufacturers—such as Voith Hydro, Andritz Hydro, GE Renewable Energy, and Dongfang—were examined to obtain technical statistics and information regarding current industry standards.

1.3.1 Evaluation of the global PSP market

Several published reports, particularly recent ones (published after 2020) by international organizations such as the International Forum on Pumped Storage Hydropower (IFPSH), the International Hydropower Association (IHA), the International Energy Agency (IEA), and the National Hydropower Association (NHA), were reviewed in order to gather information on global PSP market initiatives and the changes implemented to increase PSP deployment in their respective countries.

In addition, the U.S. Energy Information Administration (USEIA), the China Energy Portal, the German Energy Storage Systems Association (BVES/GESSA), the Asia Foundation, and the Federation of Electric Power Companies of Japan (FEPC/FEPJ) were also reviewed to obtain information on PSP development in those nations. To gain a thorough grasp of the global PSP industry, current publications in international journals were also examined.

Finding and evaluating various successful international PSP markets was the main goal of the evaluation of the global PSP market. It is anticipated that the evaluation of these global markets may provide valuable information on how they operate, the projects they have undertaken, and the modifications made to boost PSP deployment. More precisely, the evaluation and review concentrated on understanding PSP market goals, the grid services that PSP is providing in the respective countries, the institutional context surrounding the PSP market, the policy and regulatory scenarios existing in those nations, how the PSP market is evolving, how PSP is helping the integration of RE into the power grid, operating business models, and the pricing mechanisms followed for PSP in various countries, among other factors.

1.3.2 Global PSP inventory

Taking into account factors such as project identity and location, operational status, power capacity, general layout, installed electromechanical (E&M) equipment, suppliers, ownership, and the operating agency, an inventory of selected functioning PSPs across different countries was compiled. Additionally, a number of online sites were thoroughly investigated and analyzed to obtain further information regarding PSP project performance, difficulties encountered, business strategies, and other limitations faced by the projects. Contact information for project owners, contractors, suppliers of E&M equipment, and relevant electricity or energy authorities was also retrieved from online sources and directories to acquire comprehensive data and information on various PSP projects.

1.3.3 Evaluation of Ongoing PSP Development in Indian

The necessary data on PSP was requested from various developers, the Central Electricity Authority (CEA) of India, the applicable state agencies, and other pertinent organizations. The following elements were the main emphasis of the evaluation and review of current PSP operations in India: (i) planned and ongoing PSP initiatives in various states. All available resources were utilized for this purpose, with an emphasis on evaluating the achievements made, difficulties faced, and lessons learned during the PSP development process; (ii) attempts were made to determine the financial limitations, regulatory bottlenecks, and other obstacles preventing PSP projects in India from being carried out smoothly; and finally, (iii) to comprehend how equipment manufacturers, government organizations, private organizations, and other stakeholders have contributed to the growth of PSP in India.

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CHAPTER 2: TECHNOLOGICAL DEVELOPMENT IN PUMPED STORAGE HYDROPOWER

2.1 OVERVIEW

Despite being similar to traditional hydropower projects, Pumped Storage Hydropower (PSP) projects differ primarily in their functionality and design. PSP systems employ two reservoirs—either natural or man-made—situated at a desired head difference. Tunnels or penstocks of the shortest possible length are used to connect these two reservoirs, the upper and the lower (Hino and Lejeune, 2012). During operation, a pump-turbine located in the powerhouse facilitates the lifting of water from the lower reservoir to the upper reservoir. The primary feature of a PSP is that when excess energy is available during off-peak hours, water is pumped from the lower reservoir to the upper reservoir. Conversely, during periods of peak demand, water from the upper reservoir is released through a hydraulic turbine to produce electricity, and the discharged water is stored in the lower reservoir (Blakers et al., 2021; Kumcu and Wahidi, 2019; Barbour et al., 2016; Rehman et al., 2015; Steffen, 2011).

This section discusses the latest developments in PSP technology as well as the various types of PSP technologies currently available.

2.2 TYPE OF PSP - BASED ON LAYOUT

According to the layout, location, and water resources, pumped storage schemes (PSP) can be divided into three categories as listed below (CEA 2024 Guidelines for PSP) (Figure 1):

(i) **On-stream Pumped Storage:** Both reservoirs are situated on a river, stream, or nallah.

(ii) **Off-stream Open Loop Pumped Storage:** One reservoir is situated on a river, stream, or nallah, while the other reservoir (the off-stream reservoir) is located where there are no rivers, perennial streams, or perennial nallahs. Whenever an off-stream reservoir is situated on top of a non-perennial stream or nallah, appropriate measures must be taken to redirect the stream or nallah downstream and/or transfer water from the non-perennial source to its downstream via a dam, barrage, embankment, etc. Water from a dependable source must be used for the initial filling of the reservoir and to recover evaporation and recirculation losses.

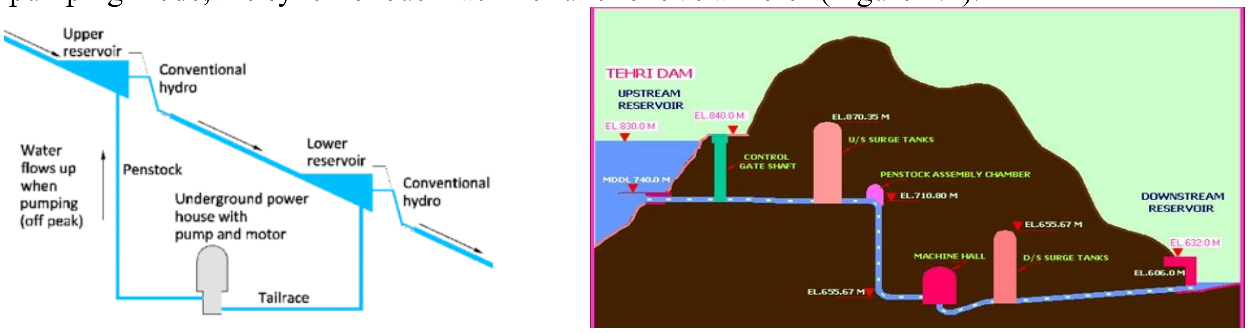
(iii) **Off-stream Closed Loop Pumped Storage:** Neither reservoir is situated on a river, perennial stream, or perennial nallah. If a reservoir is located on top of a non-perennial stream or nallah, appropriate measures must be taken to redirect the stream or nallah downstream and/or release water from the non-perennial source downstream via a dam, barrage, embankment, etc. Water from a dependable source must be used for the initial filling of the reservoirs and to recover evaporation and recirculation losses.

2.3 CONFIGURATION OF PSP BASED ON SPEED

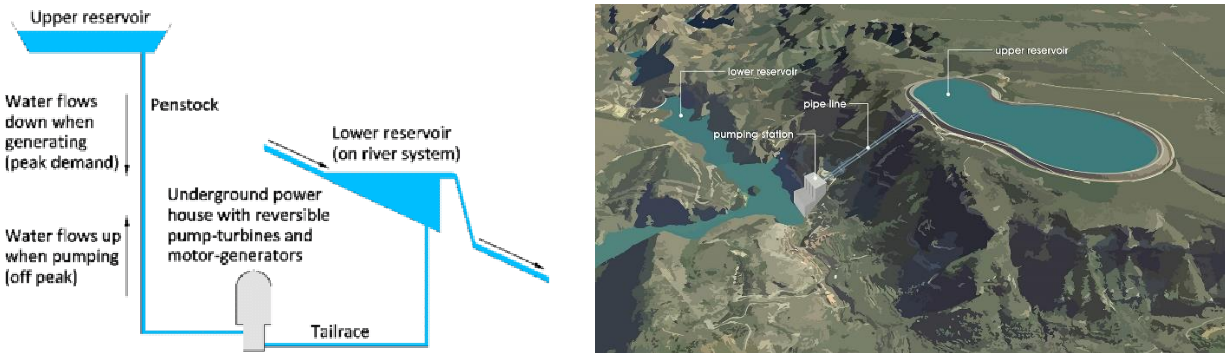
Pumped storage technology is categorised broadly in to two categories; Fixed spped and variable speed PSP (Figure 2.1).

2.3.1 PSP Technology with Fixed Speed

Fixed-speed technology is the foundation of many PSP facilities currently in operation worldwide. In these plants, a synchronous machine—which typically operates in synchronization with the grid frequency—serves as the motor-generator. While the PSP is in pumping mode, the synchronous machine functions as a motor (Figure 2.2).



(a) On-stream pumped storage scheme



(b) Off-stream open loop pumped storage scheme

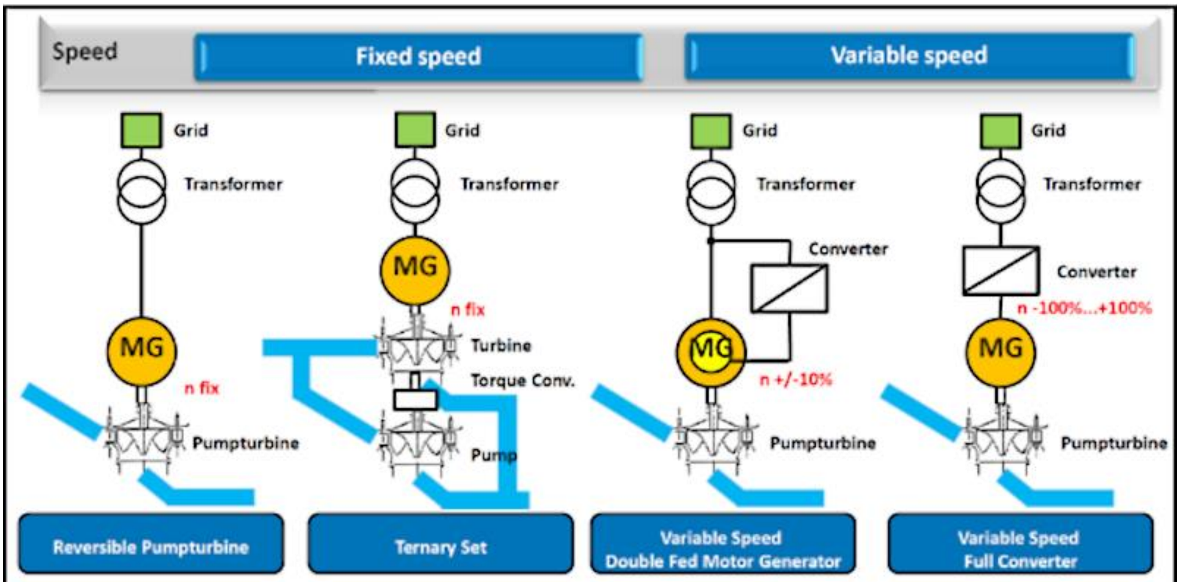
(c) Off-stream closed loop pumped storage scheme

Figure 2.1: General layout of Pumped Storage Schemes (PSP)

With rated power outputs ranging from 30% to 100%, the majority of current fixed-speed PSPs can function effectively in generation mode. In practice, many fixed-speed PSP units usually operate at more than 60% of their rated power output to ensure smooth turbine operation and minimize unnecessary damage to the unit. Generally, operating the unit between 40% and 60% of its rated power may lead to decreased water flow, which can cause vibrations and increased cavitation.

Fixed-speed PSP units can provide spinning reserve and regulation services while operating in generating mode. However, because they are unable to adjust their pumping power, they cannot perform regulation services in pumping mode (Koritarov et al., 2022). Despite this, fixed-speed PSP technology is considered highly adaptable in generating mode. With the aid of modern advancements, the next generation of sophisticated fixed-speed PSP plants can respond more rapidly in terms of ramp rates, mode change durations, and operating ranges. They can also operate with lower minimum loads and a broader working head range[2].

In addition to traditional fixed-speed PSP, the technology offers two further configurations, which can be summarized as follows: (a) Ternary PSP Technology and (b) Quaternary PSP Technology.



Reversible Pumpturbine	Ternary Set	Variable Speed Double Fed Motor Generator	Variable Speed Full Converter
Most compact design	Most complex design, requires very deep excavation and with complex water conductor system	Large powerhouse volume required due to AC excitation system	Full size convertor
Most widely employed technology with max. installations globally	Only few installations globally	More than 10 installations across globe	Few installation across globe. Currently, limited to <100MW unit size
Most economical solution	Most expensive solution	Expensive solution	Very expensive

Figure 2.2: Fixed-speed and variable speed configuration in PSP Technology
(Source: Koritarov et al., 2022).

[2] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Innovative_PHS_operation_2020.pdf

(a) Ternary PSP technology

Prior to the development of the reversible pump-turbine, a typical Ternary PSP technology arrangement consisted of three components: a motor-generator, a separate turbine, and a separate pump. However, the "hydraulic short circuit" characteristic of cutting-edge modern ternary technology provides for exceptional operational flexibility. In this design, the pump and turbine can be mechanically separated using a clutch; yet, when they are connected, they can both rotate in the same direction. In Ternary PSP, this function is referred to as "mixed mode," "hydraulic short circuit," or "hydraulic bypass." There are multiple motor-generator, pump, and turbine configurations possible with ternary PSP technology. Two ternary plant layouts with hydraulic short-circuit capabilities are shown in Figure 2.3.

The primary benefit of Ternary PSP technology is that the unit's power can fluctuate continuously between -100% and 100% of its rated power, achieved through controlled flow within the turbine and the adjustment of power required to run the pump. In generating mode, ternary units typically function as fixed-speed PSP units, at which point the pump is disconnected. Conversely, they can operate in hydraulic short-circuit mode during pumping, with the clutch connecting both the turbine and the pump. While operating in short-circuit mode involves some efficiency loss, it allows the unit to provide precise power regulation to the grid. This capacity to run the pump and turbine concurrently in hydraulic short-circuit mode is what facilitates the system's exceptional operational flexibility.

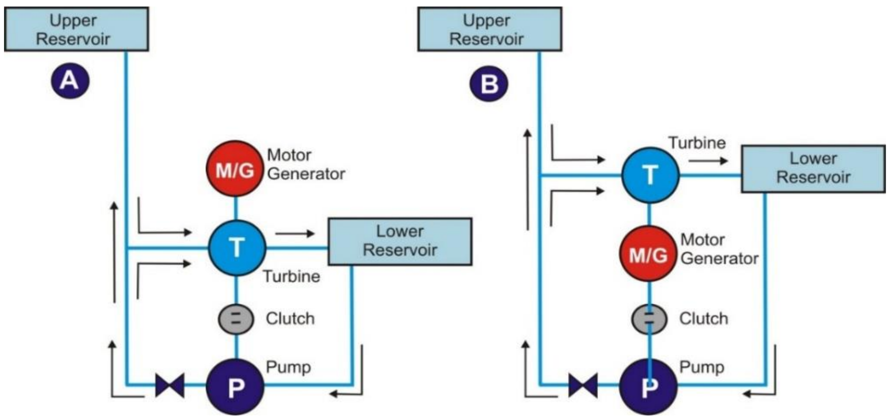


Figure 2.3: Ternary PSP plant configurations with Hydraulic Bypass
(A) a motor-generator is located on the top, above the turbine and the pump and
(B) when a motor-generator is located between the turbine and the pump (Source: Koritarov et al., 2013b)

(b) Quaternary PSP Technology

The configuration of quaternary PSP technology consists of four distinct parts. While quaternary technology features a power converter, motor, and pump on one shaft and a turbine and generator on another, ternary technology uses a single shaft for the pump, turbine, and motor-generator (Figure 2.4).

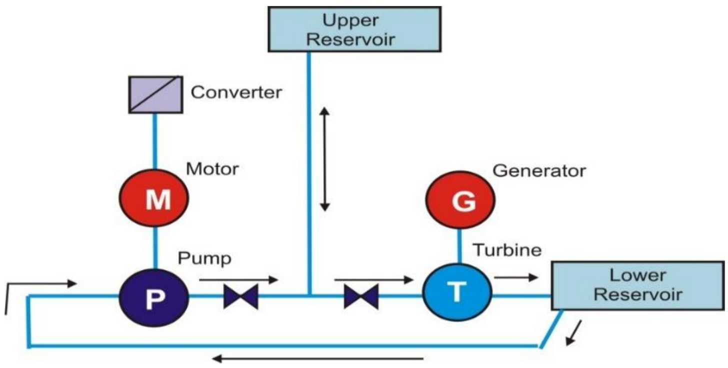


Figure 2.4: Quaternary PSP plant configuration with Hydraulic Short Circuit
(Source: Koritarov et al., 2022).

It is possible to design quaternary technology to operate in a hydraulic short circuit. As a result, quaternary systems can operate with nearly complete flexibility within a range of -100% to +100% of the generating unit's rated power. During hydraulic short-circuit operation, a quaternary unit can run the pump and the turbine simultaneously. Additionally, by regulating the flow through the turbine and the power supplied to the motor via the converter, the power drawn from the grid can be precisely controlled in pumping mode. Consequently, the quaternary PSP system offers superior operational flexibility in both pumping and generating modes (Koritarov et al., 2022).

2.3.2 Variable Speed PSP Technology

Toshiba Corporation originally introduced variable-speed PSP technology in the early 1990s when they used power converters based on semiconductor technology to transform a single fixed-speed unit at the Yagisawa PSP plant in Japan into a variable-speed unit. In Japan, power demand is minimal at night while baseload generation remains constant; consequently, the power system requires flexibility during nighttime hours. Pumping extra load at night via PSP units allows for more must-run baseload capacity. Additionally, by generating power in accordance with demand, PSP plants offer significant flexibility to grid operations. Variable-speed PSP units can adapt to changes in the amount of grid power used for pumping, allowing these units to offer regulatory services while in pumping mode. The two primary types of variable-speed PSP technology are Doubly Fed Induction Machines (DFIM) and Converter-Fed Synchronous Machines (CFSM) (Koritarov et al., 2022).

(a) Doubly fed induction machine (DFIM)

A frequency converter is used by the DFIM to regulate the machine's rotational speed (Koritarov et al., 2013a). The converter's capacity does not need to equal the DFIM unit's entire rated power, as the speed is adjusted within a relatively small range—typically about ±10% around the nominal speed. Only a portion of the DFIM unit's total power is allocated to the frequency converter (Koritarov et al., 2022). For instance, the Frades II PSP in Portugal utilizes variable-speed turbines and a doubly fed induction machine. This 780 MW project is one of the few large-scale PSP plants using variable-speed technology (XFLEX HYDRO, 2019a). In a grid with approximately 20% wind generation, the facility helps control frequency (IHA, 2018). Variable-speed machines in PSP plants enable a wider operating range, quicker reaction times, and higher efficiency (Voith, 2019; IRENA, 2020).

(b) Converter-fed synchronous machine (CFSM)

A synchronous machine is used as a motor-generator in the Converter-Fed Synchronous Machine (CFSM) configuration. In a CFSM, the motor-generator is managed by a "full-size" frequency converter, whose dimensions correspond to the generating unit's total capacity. Due to the expense of power electronics, CFSM technology was historically considered economically feasible only for PSP units with capacities under 100 MW (Aubert et al., 2014). While DFIM technology uses a smaller converter, the full-size frequency converter in CFSM machines allows for a greater range of power factor and speed modifications. For example, a 5 MW variable-speed pump-turbine equipped with a full-size frequency converter (CFSM) and optimization software is planned for the Z'Mutt PSP in Switzerland to improve flexibility services (IRENA, 2020; XFLEX HYDRO, 2019b). Compared to fixed-speed PSP units with identical setups, adjustable-speed PSP machines require a comparatively higher capital investment due to the additional power electronics and supporting equipment. Combinations of fixed-speed, DFIM, and CFSM adjustable-speed PSP units are displayed in Figure 2.2 (Koritarov et al., 2022)

2.3.3 Capability of Variable Speed PSP Technology to Provide Primary Responses while in Pump Mode

When compared to fixed-speed PSP devices, variable-speed (also known as adjustable-speed) PSP technology generally offers a number of operational benefits. The following is a summary of the main advantages of adjustable-speed units:

(i) **Improved Efficiency:** In generating mode, adjustable-speed PSPs demonstrate marginally improved operational efficiency, especially when operating at partial load. This is due to the machine's ability to optimize its rotational speed for a specific head and turbine flow rate.

(ii) **Pumping Mode Regulation:** Adjustable-speed PSPs can offer regulation services while operating in pumping mode because these devices can vary the amount of power consumed during the pumping cycle. Typically, adjustable-speed PSP machines can operate between 70% and 100% of their rated pumping capacity.

(iii) **Adaptable Voltage Support:** These units offer more adaptable voltage support for the power system. This is a result of their frequency converter-based control, which allows for the electrical decoupling of active and reactive power.

(iv) **Greater Working Range:** Compared to fixed-speed units, adjustable-speed PSPs have a broader operating range, as they can utilize lower minimum loads of approximately 20–30% of their rated capacity. Generally, adjustable-speed machines run more smoothly and sustain less wear and tear since they can function at optimal or nearly optimal speeds even when partially loaded. Consequently, adjustable-speed systems often have a longer projected lifespan than fixed-speed devices.

(v) **Grid Stability:** In the event of grid disruptions, adjustable-speed units offer superior dynamic response features compared to fixed-speed units. This results in fewer frequency drops during unexpected transmission or generator failures and enhances overall power system stability.

Table 2.1 provides an overview of the typical operating capabilities of ternary, fixed-speed, and doubly fed induction machine (DFIM) adjustable-speed PSP technologies. Pelton turbines are commonly utilized in Ternary systems; however, Francis or other turbine types may also be employed, depending on the site's hydraulic conditions. Comparatively speaking, variable-speed systems are generally less expensive than ternary PSP units, as the latter requires additional mechanical equipment (Table 2.1). For instance, the Hongrin-Léman (240 MW) plant in Switzerland and the Kops II (450 MW) plant in Austria employ ternary systems. At Kops II, the installation of three ternary units allows a 180 MW turbine and a 150 MW pump to operate simultaneously (Pöyry, 2014).

Table 2.1: Typical Operating Capabilities of Ternary, Fixed speed and Doubly fed induction machine Adjustable speed PSP Technologies

(Source: DOE b (U.S. Department of Energy). 2016)

Capability	**Ternary PSP with Hydraulic Bypass and Pelton Turbine**	**Fixed-Speed PSP**	**DFIM Adjustable-Speed PSP**
Generation mode			
Power output (% of rated capacity)	0–100%	30–100%	20–100%
Standstill to generating mode (seconds)	65	70	75-85
Generating to pumping mode (seconds)	25	240–420	240–415
Frequency regulation	Yes	Yes	Yes
Spinning reserve	Yes	Yes	Yes
Ramping/load following	Yes	Yes	Yes
Reactive power/voltage support	Yes	Yes	Yes
Generator dropping	Yes	Yes	Yes
Pumping Mode			
Power consumption (% of rated capacity)	0–100%	100%	60–100% (75–125%)*
Standstill to pumping mode (seconds)	80	160–340	160–230
Pumping to generating mode (seconds)	25	90–190	90–190
Frequency regulation	Yes	No	Yes
Spinning reserve	Yes	No	Yes
Ramping/load following	Yes	No	Yes
Reactive power/voltage support	Yes	Yes	Yes
Load shedding (pump dropping)	Yes	Yes	Yes
* If a PSP unit is converted from fixed to adjustable speed and the same pump-turbine runner is used, its power consumption may range from 75% to 125% of the former fixed-speed power consumption (100%).			

2.3.4 Inertia constant provided by PSP and other generation source to the Grid

The primary sources of inertia in the current power system are large conventional units such as coal, gas, nuclear, and hydropower facilities that use synchronous equipment. A generator's inertia contribution, including pumped storage hydropower (PSP), is expressed as an inertia constant with a unit of seconds, $H = \frac{\frac{1}{2}J\omega_s^2}{MVA}$ MVA, where J is the moment of inertia, ω_s is the synchronous speed, MVA is the machine's power rating, and H is the inertia constant.

H is dependent on a number of variables, such as the rotating shaft's size and geometry, the rotating part's mass, the machine's speed, and the MVA rating. The inertia constant varies depending on the generation technique. Table 2.2 presents the results of a comparison between PSP and alternative generating sources.

The same inertia as the above-mentioned typical hydropower plant will be provided by fixed speed PSP. On the other hand, inertia might or might not be available for variable speed PSP.

Table 2.2: Typical Inertia Constants for Different Types of Machines (POSOCO 2022)[3]

Types of machines		Inertia constant (H) (s)
Thermal power plant	Steam turbine	4-9
	Gas turbine	1.4-4.3
Hydropower plant generator	Slow speed: <200 rpm	2-3
	High speed: >200 rpm	2-4
Nuclear power plant generator		6
Synchronous condensers	Large	3
	Small	1
Synchronous motor load		2
Diesel engine		1-3
Induction motor loads		0.5-3

2.4 INNOVATIONS IN PSP TECHNOLOGY

PSP technology has seen a number of creative developments recently. Numerous organizations, scholars, and individuals have proposed various novel PSP concepts. Koritarov et al. (2022) of the US Department of Energy and the International Forum for Pumped Storage Hydropower (IHA, 2021b) have enumerated several PSP improvements, attempting to evaluate their prospective benefits and drawbacks in comparison to traditional modern PSP facilities. Additionally, they have sought to determine whether these innovations are more cost-effective, technically feasible, and capable of providing additional operational capabilities or facilitating increased grid services compared to standard existing PSP plants. The following paragraphs provide a synopsis of these inventive PSP concepts.

[3] Source: Report on Assessment of Inertia in Indian Power System, POSOCO, Jan 2022

2.4.1 PSP with submersible pump-turbines and motor-generators

Obermeyer Hydro, Inc. is developing a PSP technology in the USA that utilizes submerged pump-turbines and motor-generators. In a traditional PSP layout, it is standard practice for the reversible pump-turbines to be submerged while the motor-generators are positioned above them, unsubmerged, within the powerhouse (Figure 2.5).

However, in the novel PSP configuration proposed by Obermeyer Hydro, Inc., no powerhouse building is required because both the pump-turbine and the motor-generator are submerged within a vertical shaft. The suggested design may require a vertical shaft or well with a diameter of two to three meters (Obermeyer et al., 2019). The PSP arrangement using submersible motor-generators and pump-turbines is a promising technique; this novel concept could lower PSP costs, reduce the time required to establish plants, and potentially mitigate the risks involved in development. Depending on the scalability of these plant sizes, this technology could support several potential sites ranging from micro to medium-scale projects. Furthermore, reversible pump-turbines equipped with flow inverters are considered highly efficient (Koritarov et al., 2022).

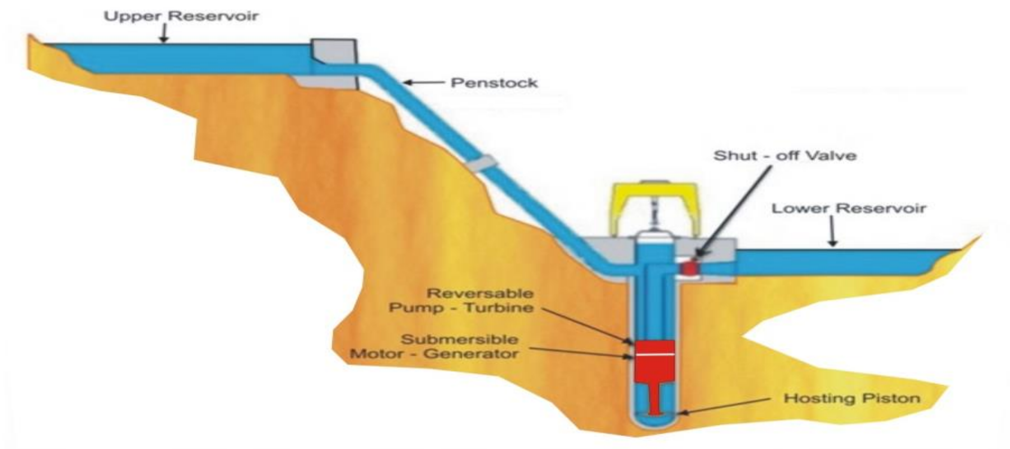


Figure 2.5: PSP using submersible pump-turbines and motor-generators
(Source: Obermeyer Hydro, Inc., Obermeyer et al. 2019)

2.4.2 Small PSP with reservoirs of corrugated steel and floating membranes

Shell Energy North America (SENA) proposed a small modular PSP technology utilizing reservoirs constructed with floating membranes or corrugated steel. This innovative technology can be implemented in both open-loop and closed-loop PSP arrangements. The design suggests using corrugated steel for the upper reservoir and a floating membrane for the lower reservoir, which would float within a larger body of water, such as a lake (Figure 2.6).

In a closed-loop PSP setup, water is cycled between the upper and lower reservoirs. The water within the lake where the lower floating membrane reservoir is situated does not mix with the water inside the lower reservoir itself. At Pearl Hill, SENA proposed a closed-loop PSP system with 5 MW of generating capacity and 9 MW of pumping capacity. Additionally, SENA designed the Pearl Hill PSP to store energy for six hours, providing a total of 30 MWh of generation (FERC, 2019).

2.4.3 PSP in Abandoned Open-pit mine

A PSP plant can be developed using open-pit mines that have been closed after mining operations are completed. An abandoned open pit situated at a suitable site at a higher elevation can serve as the upper reservoir, while a similar pit at a lower elevation can be used as the lower reservoir (Figure 2.7).

Using abandoned open pits can significantly reduce construction costs because excavation is not required to create the reservoirs. The primary concern for ensuring the viability of this solution is assessing suitability based on geological parameters, slope stability, and the water-tightness of the reservoirs. It is well-established that discontinuities in the rock mass can lead to slope instability when saturated, as they create internal water forces (Raghuvanshi et al., 2014; 2019).

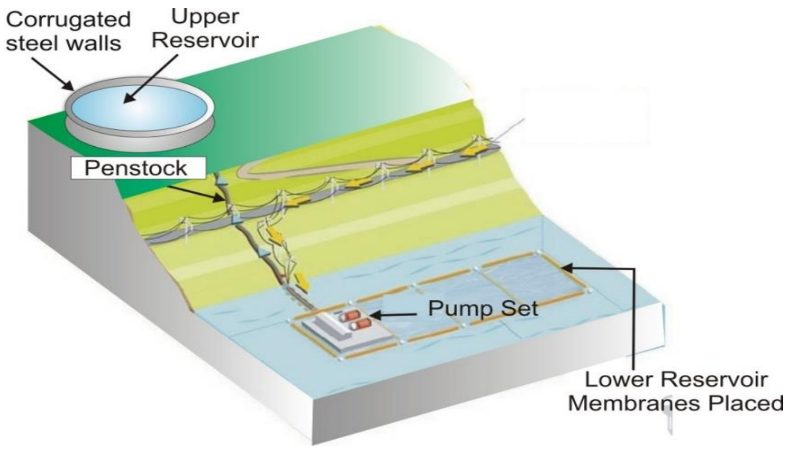


Figure 2.6: Small PSP with reservoirs of corrugated steel and floating membranes
(Source: Balducci et al., 2018)

Figure 2.7: A conceptual layout of a PSP in abandoned Open-pit mine
Base image: Ranger Uranium Mine Northern Territory Australia
(Source: https://media.istockphoto.com/id/153065178/photo/uranium-mine.jpg?s=1024x1024&w=is&k=20&c=QutY9icYD4ZeD3IadBEDI41f2T1ab8kchjDCa3UMj-0=)

There is already a 1,728 MW PSP plant in the UK called Dinorwig, which was commissioned in 1984. For this closed-loop PSP project, an abandoned slate quarry open pit was utilized as the lower reservoir (https://www.fhc.co.uk/en/power-stations/dinorwig-power-station/; Koritarov et al., 2022). Similarly, the Kidston PSP, which is currently under development in Australia, will be built on the site of an abandoned open-pit gold mine (IFPSH, 2021). The Kidston closed-loop PSP project will employ two existing pits at different elevations for the upper and lower reservoirs. Additionally, the 1,300 MW Eagle Mountain PSP project is being planned for construction at a former iron ore mine in the United States. This project will also utilize two existing open pits at varying elevations for the upper and lower reservoirs (Koritarov et al., 2022).

Furthermore, Coal India Limited (CIL) has initiated research for the development of PSP after identifying 24 abandoned mines across its various subsidiary firms in several states. A Pre-Feasibility Report (PFR) for a 100 MW PSP project has already been prepared. Similarly, Neyveli Lignite Corporation India Limited (NLCIL) has also commenced PSP development efforts [4].

2.4.4 PSP Development in Abandoned Underground mine

PSP projects in former mines have attracted significant interest because they have the potential to provide technical, financial, and environmental advantages by repurposing these historic locations for renewable energy storage (Madlener and Specht, 2020). The fundamental concept behind exploiting abandoned underground mines involves utilizing existing underground pits, tunnels, and galleries as the lower reservoir for the PSP, while constructing an upper reservoir on the surface (Figure 2.8).

Implementing this design offers several key advantages. The existence of an abandoned underground mine provides an opportunity to develop PSP in regions with flat topography, where establishing a traditional PSP plant would otherwise be impossible. Furthermore, utilizing pre-existing, abandoned underground mining voids can significantly lower the costs associated with constructing underground caverns in such flat areas (Koritarov et al., 2022).

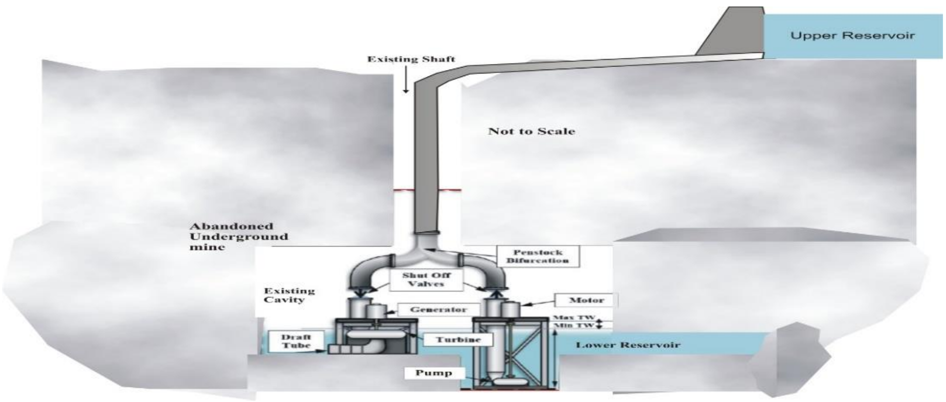


Figure 2.8: A conceptual layout of an underground powerhouse in a coal mine
(Source: Witt et al., 2015).

[4] https://www.nlcindia.in/investor/DIPAM Presentation Nov 24.pdf

The abandoned underground mine PSP concept involves constructing or utilizing an existing open-pit surface reservoir as the upper reservoir, while using the pits, tunnels, and galleries of an existing mine as the lower reservoir. Additionally, existing subterranean voids can be repurposed to house an underground powerhouse (Koritarov et al., 2022). To guarantee water retention, effective recycling, and the structural stability of the subterranean cavities, engineering geology, hydrogeology, in-situ stresses, and overall stability conditions must be carefully examined. A conceptual layout of an underground powerhouse in a coal mine is presented in Figure 2.8 (Witt et al., 2015; Colas et al., 2023).

Feasibility studies and conceptual designs are currently being conducted for several potential projects, including the Aland and Pyhäsalmi mines in Finland, the Martelange slate mine in Belgium (Kitsikoudis et al., 2020), and abandoned coal mines in Germany (such as Prosper-Haniel in Bottrop, Porta Westfalica, or the Harz mines) and Australia (the Centennial Fassifern coal mine). In the United States, the Oak Ridge National Laboratory (ORNL) investigated the viability of utilizing decommissioned coal mines for small modular PSP plants in 2015 (Witt et al., 2015). Furthermore, potential applications of this technology in the state of Indiana are being researched by Carbon Solutions, LLC, in partnership with Indiana University–Purdue University Indianapolis (IUPUI) (Lu et al., 2017; Colas et al., 2023).

2.4.5 Hybrid PSP and wind plant

The German company Max Bögl Wind AG (Max Bögl) has developed a novel PSP concept that involves constructing small concrete reservoirs at the bases of wind turbines, ideally situated on elevated terrain. In this design, the upper reservoir is a multi-part structure built around the foot of the wind turbine, which is then connected via a penstock to a lower reservoir located at the base of the slope (Figure 2.9).

Figure 2.9: Layout of Hybrid PSP and wind plant – Photograph showing Gaildorf Pilot Project in Germany
(Source: https://www.mbrenewables.com/en/pilot-project/)

Max Bögl constructed a hybrid PSP and wind plant pilot project in Gaildorf, Germany. This pilot project features four wind turbines, each supported by a concrete reservoir at its base. The four wind turbines, each with an installed capacity of 3.4 MW, provide a combined capacity of 13.6 MW. The integrated PSP is a closed-loop system with an installed capacity of 16 MW. Each of the four upper reservoirs built at the foot of the wind turbines is connected to the lower reservoir via an underground penstock, utilizing a 200-meter hydraulic head between the upper and lower reservoirs.

According to Koritarov et al. (2022) and official project documentation (https://www.mbrenewables.com/en/pilot-project/), the main benefits of hybrid PSP and wind plant technology include lower investment costs due to the standardization of construction and the use of prefabricated components. Other advantages include a relatively shorter construction period, a long plant lifetime (estimated by Max Bögl to be approximately 50 years), and the potential for additional hybrid operations with other renewable resources, such as solar, alongside wind.

2.4.6 Underground PSP using tunnel-boring machines for storage excavation

Nelson Energy, LLC has proposed using a tunnel boring machine (TBM) to excavate a lower reservoir in hard, solid rock for an underground PSP plant. According to the proposal, an access tunnel is first excavated to a desired depth of approximately 2,500 feet, after which the cavities for the powerhouse and reservoir are developed. With the aid of a TBM, the lower reservoir can be excavated in a spiral pattern until the required storage capacity is achieved (Figure 2.10).

The crushed rock removed from the subterranean bedrock is transported to the surface through the access tunnel and utilized to construct a rockfill embankment for the upper reservoir at ground level. This upper reservoir can then be initially filled with water from a nearby lake, river, or other dependable source. In this manner, a closed-loop PSP system is created. As suggested by Nelson Energy, Figure 2.10 illustrates an underground PSP system utilizing tunnel-boring equipment for storage excavation (IFPSH, 2021; Koritarov et al., 2022).

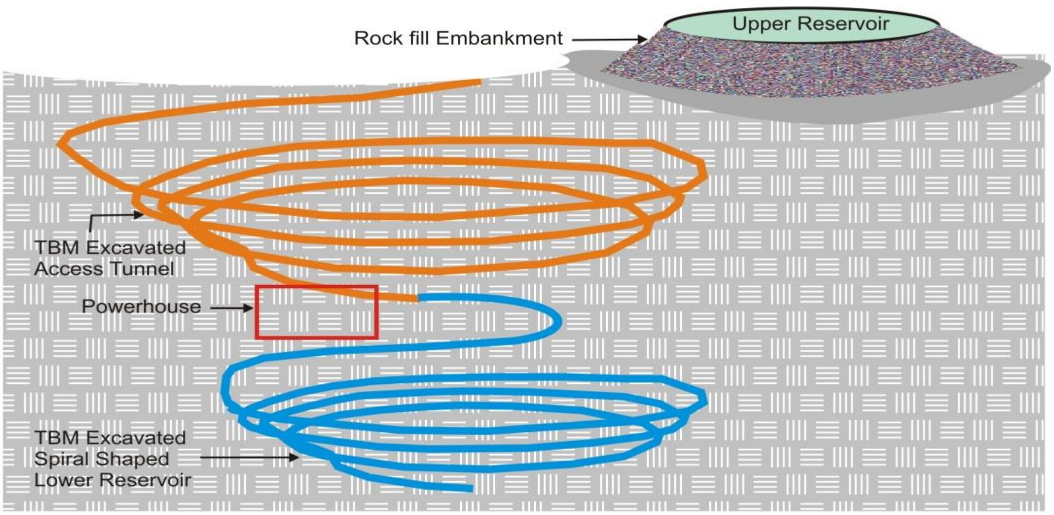


Figure 2.10: Conceptual layout of underground PSP using TBM for storage excavation, as proposed by Nelson Energy (Source: IFPSH, 2021; Koritarov et al., 2022).

Underground PSP using tunnel-boring machines for storage may offer a chance to build a PSP scheme for energy storage in flat topographic terrains where traditional PSP plants cannot be built.

2.4.7 Integrated PSP and desalination plant

The Integrated Pumped Hydro Reverse Osmosis Clean Energy System (IPHROCES), a hybrid technology combining PSP and water desalination, was developed by Oceanus Power & Water, LLC (Oceanus). This method integrates a seawater PSP plant with a reverse osmosis desalination facility (Figure 2.11).

Consequently, the technology provides a comprehensive system that combines energy storage with freshwater delivery. By integrating the desalination and PSP plants, this hybrid technology offers significant synergistic advantages. The system is economically efficient because the PSP plant provides the energy required for the seawater desalination process. Furthermore, the integrated system generates revenue by supplying a substantial volume of fresh, potable water (Koritarov et al., 2022).

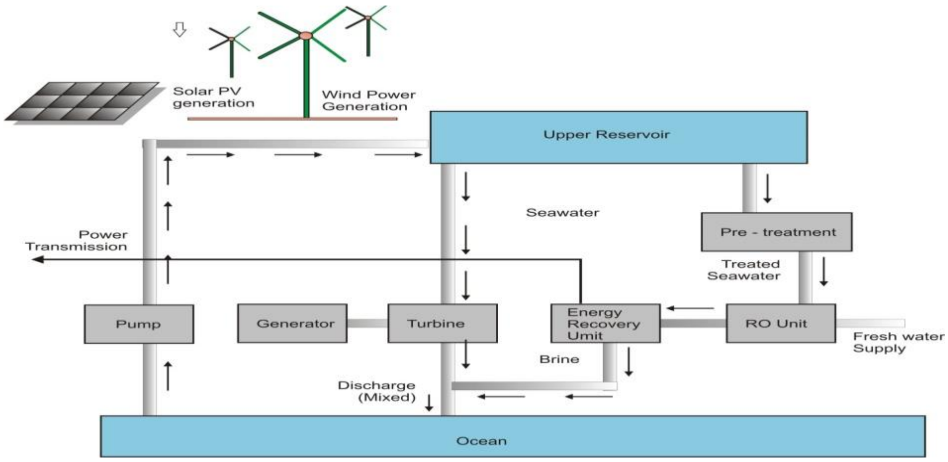


Figure 2.11: General Layout of Integrated PSP and desalination plant
(Source: Oceanus Power & Water, LLC; Koritarov et al., 2022)

2.4.8 Deep Sea PSP – StEnSea System

The Fraunhofer Institute for Energy Economics and Energy System Technology developed the concept of deep-sea pumped hydro storage, which utilizes massive hollow concrete containers on the seafloor as the lower reservoir and the surrounding seawater as the upper reservoir (Figure 2.12). This innovative offshore pumped hydro energy storage (PSP) method stores energy in hollow concrete spheres by harnessing the hydrostatic pressure found in deep water. These spheres are positioned at depths between 600 and 800 meters below the sea surface. Following an initial research study to validate the technology through field testing, this system became known as the StEnSea (Stored Energy in the Sea) system.

In the StEnSea system, a hollow concrete sphere is positioned deep underwater on the seabed. When wind or solar PV systems generate excess electricity and wholesale prices are low, a pump-turbine pumps water out of the hollow sphere (https://www.iee.fraunhofer.de/en/topics/stensea.html). During periods of high electricity demand and high prices, water is allowed to return to the hollow sphere through the pump-turbine to generate electricity. The interior volume of the concrete sphere remains at or below atmospheric pressure (Hahn et al., 2017).

In this configuration, the PSP plant is situated adjacent to a wind or solar power plant, creating an integrated connection between the variable renewable energy (VRE) facility and the storage system (Figure 2.13). This allows the PSP to serve as on-site storage for surplus energy, effectively helping to overcome the intermittent nature of the VRE supply.

2.4.9 Using Sea as lower reservoir amd placing upper reservoir on coastal high land

In this type of energy storage system, the sea serves as the lower reservoir. Seawater is pumped uphill to an upper reservoir during periods of low energy demand and later released through turbines to generate electricity when demand is high. This configuration essentially functions as a seawater-based PSP, as opposed to conventional freshwater-based systems.

The 30 MW Okinawa Yanbaru Seawater-based PSP in Japan was the world's first such facility, remaining operational from 1999 to 2016. The upper reservoir had a storage capacity of 564,000 m³ of seawater. The project utilized the Pacific Ocean as its lower reservoir, featuring an effective head of 136 m and a maximum flow rate of 26 m³/s. The facility's powerhouse, which contained the pump-turbine, was located underground.

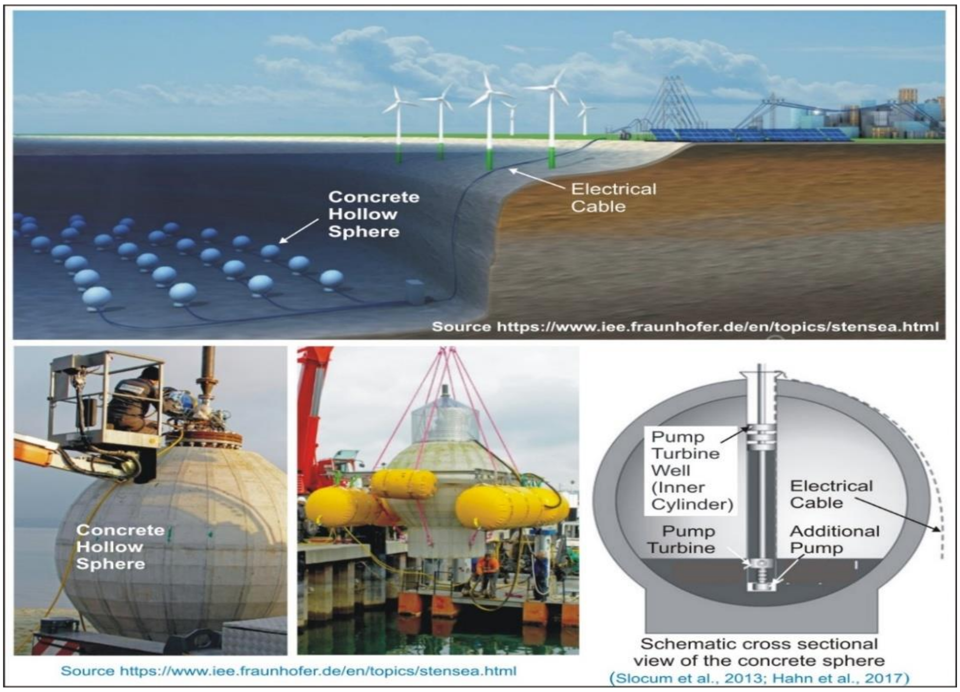


Figure 2.12: Deep Sea PSP – StEnSea System
(Source: IFPSH, 2021; Hahan et al., 2017

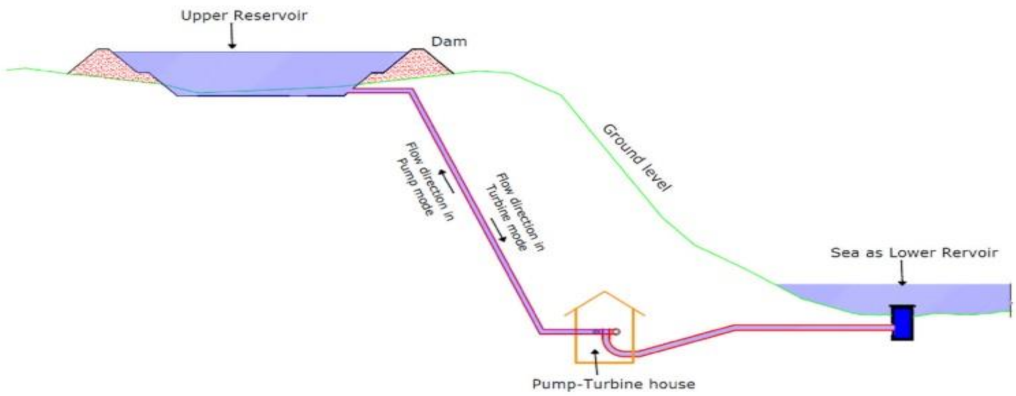


Figure 2.13: A conceptual layout of seawater PSP system – upper reservoir on coastal highland (Mode I)
(Source: Pradhan et al., 2021)

The upper reservoir was constructed approximately 600 m from the coastline and 150 m above sea level. It featured an octagonal planar shape with a maximum width of 252 m. The reservoir had a maximum depth of 25 m and an effective storage capacity of 564,000 m³. To protect the environment, the entire inner surface of the reservoir was covered with an impermeable liner to prevent seawater from leaking and damaging the surrounding vegetation

https://www.esru.strath.ac.uk/EandE/Web_sites/17-18/cumbrae/Seawater pumped hydro.html - content11-7y (Fujihara et al., 1998).

Figure 2.14: Okinawa PSP facility on Pacific Ocean at Okinawa Island in Japan

2.4.10 PSP coupled with VRF as storage on site

The Kidston PSP project in Australia is a prime example of an integrated PSP and VRE (Variable Renewable Energy) on-site storage system. Combining 320 MW of solar PV and 150 MW of wind power, the proposed 250 MW large-scale PSP will store energy for 8–10 hours (Iannunzio, 2018).

By storing solar energy during the day and releasing it through the hydro system during morning and evening peak hours, the project is anticipated to deliver dispatchable and dependable renewable electricity. This configuration can mitigate the risk of rising nighttime electricity costs when PSP facilities are typically "recharging," and it minimizes losses related to importing electricity from the grid (Energy Magazine, 2018; IRENA, 2020).

Another example is the 1,200 MW Pinnapuram PSP project in Andhra Pradesh, India. This project integrates both wind (550 MW) and solar (1,000 MW) components. The project is standalone in nature, with both reservoirs situated away from existing natural water systems. It is expected to provide a storage capacity of 9,600 MWh and operate at peak capacity for eight hours per day (https://greenkogroup.com/ap01.php).

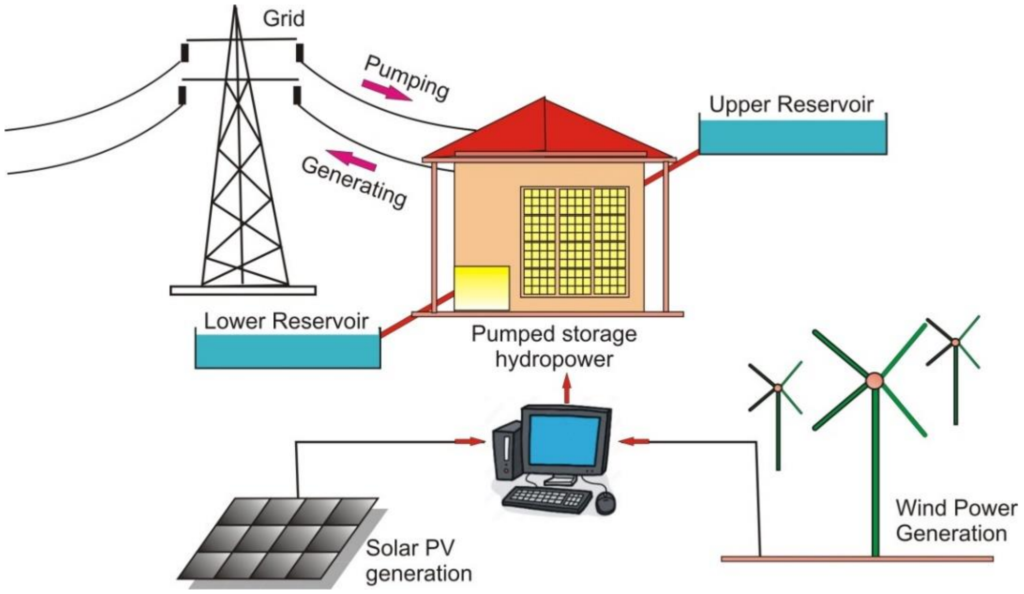


Figure 2.15: PSP coupled with VRF as storage on site

2.4.11 PSP coupled with Hybrid multiple systems including Battery storage

PSP can be designed with various hybrid configurations and connected to multiple energy sources. It can incorporate battery storage, traditional hydropower, wind, and solar power, among other renewable energy sources (Figure 2.16). Such integration of a hybrid energy mix can be planned and developed in accordance with specific requirements for energy storage, grid stability, and power loss reduction, while guaranteeing a stable and reliable electricity supply.

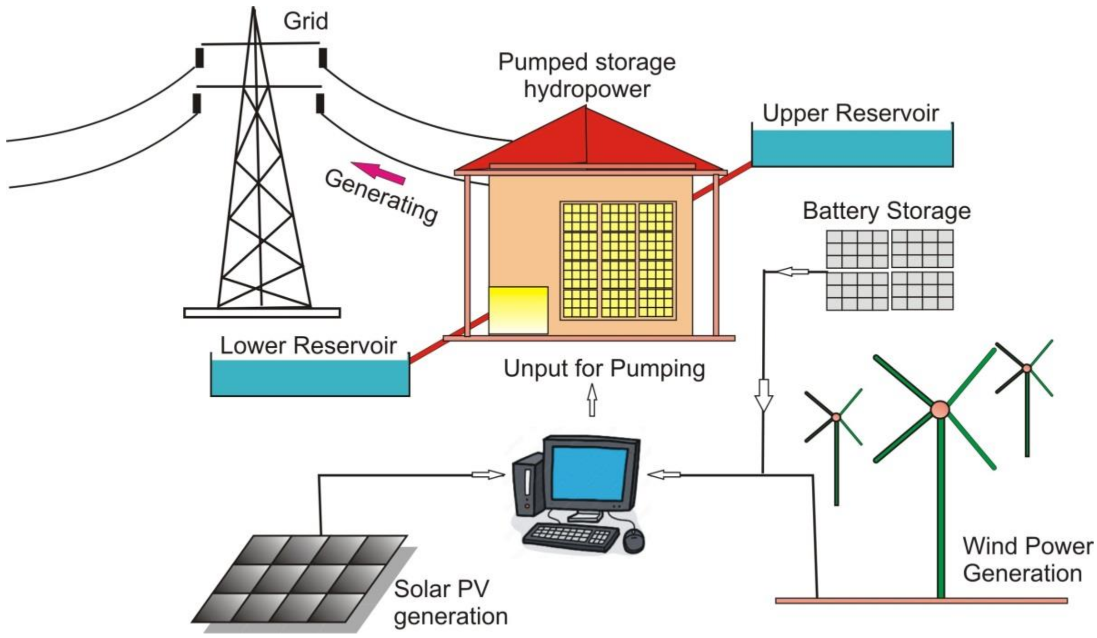


Figure 2.16: Conceptual configuration for PSP integrated with Hybrid multiple systems

A notable example is the West Kauai Energy Project in Hawaii, USA, which is currently being developed by the AES Corporation and the Kauai Island Utility Cooperative. This hybrid PSP system integrates a small conventional hydropower plant (4 MW) and a small PSP plant (20 MW) with a solar PV array (35 MW) and battery storage (35 MW, 70 MWh).

2.4.12 PSP technologies coupled with Floating photovoltaic (PV) systems

To integrate VRE technology with PSP, floating photovoltaic (PV) systems can be deployed on the surface of either the upper or lower reservoir (Figure 2.17). This hybrid model benefits from utilizing existing high-voltage grid connections. There are a number of advantages to floating PV schemes, which deploy solar panels on the water instead of on land:

(i) **Enhanced Performance:** This configuration boosts solar cell performance because the cooling effect of the water prevents cells from overheating (World Bank Group, ESMAP and SERIS, 2019).

(ii) **Grid Integration:** The existing transmission lines are directly integrated with storage capabilities, enabling continuous, dispatchable, and adaptable power generation from the system.

(iii) **Land Conservation:** Installing solar PV panels on the water surface of the PSP reservoir saves an equivalent amount of land for other productive uses.

(iv) **Operational Efficiency:** The management of stored water in the reservoir offers additional synergistic advantages for energy production.

(v) **Reduced Evaporation:** Suspending solar panels above the reservoir's surface can significantly decrease evaporation losses.

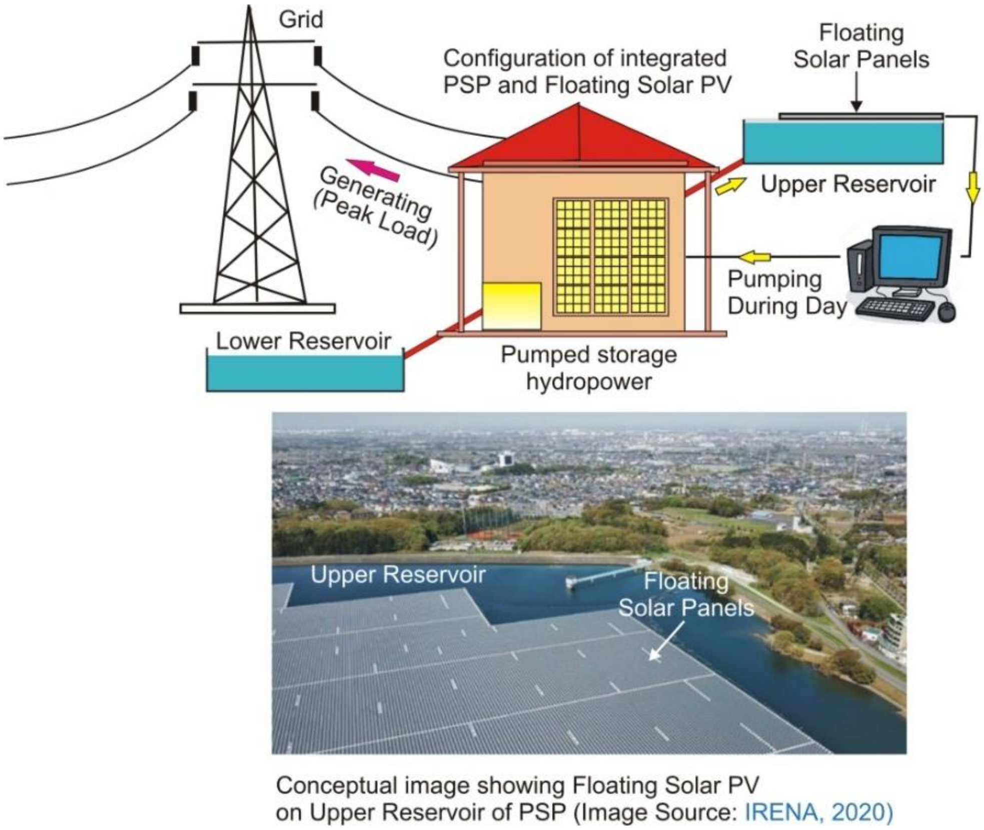


Figure 2.17: PSP facility coupled with Floating Solar PV

Example; PSP coupled with floating PV system at Montalegre, Portugal. This project is the world's first hybrid PV and hydroelectric dam power plant system. Hydropower is saved for usage during evening peak demand by using solar panels to generate electricity during the day (Carr, 2017). The floating solar PV project adds 220 kWp to the plant's 68 MWp total capacity (Prouvost, 2017). The hybrid plant generates about 300 MWh per year (EDP, 2017; IRENA, 2020).

2.4.13 Solid Gravity Energy Storage (SGES) Technology

Solid Gravity Energy Storage (SGES) is a mechanical energy storage system based on gravitational potential energy that exists in a variety of forms. It is highly cycle-efficient, adaptable to most types of terrain, and reasonably priced. Tong (2022) summarized the limited systematic research on different forms of SGES currently available in the literature, which are presented in Table 2.3.

Table 2.3: SGES Types and Technologies' performance[5]

[5] European Commission, Joint Research Centre, Roca Reina, J.C., Volt, J., Carlsson, J., Ince, E., Letout, S., Mountraki, A., Eulaerts, O.D. and Grabowska, M., Clean Energy Technology Observatory: Novel Energy Storage in the European Union - 2024 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/6320829, JRC139267.

	Type of SGES	Storage capacity (MWh)	Cycle efficiency	Location adaptability	Response time	Lifetime (years)	Modul-arity	TRL
(a)	Tower	20 – 5,000	90	Good	Seconds	30 - 40	Good	6 - 7
(b)	Shaft	1 - 20	80 -90	Poor	Seconds	50	Poor	5
(c)	Piston	1 – 8,000	75 -80	Good	Seconds	40 - 60	Poor	3 - 4
(d)	Compressed Air Piston	-	-	-	-	-	-	-
(e)	Rope-hoisting Piston	-	-	-	-	-	-	-
(f)	Mountain Mine-Car	5 – 1,000	78	Poor	Seconds	40	Good	6 - 7
(g)	Mountain Cable-Car	1 - 20	85	Poor	Seconds	15	Good	3 - 4
(h)	Linear Electric Machine-Based	1 - 5	81	Good	Seconds	50	Good	3 - 4

In the working gravel mine known as Gamebird Pit in Pahrump, Nevada, USA, ARES Nevada is constructing a 50 MW GravityLine™ merchant energy storage plant on approximately 20 acres. Similarly, Switzerland's Energy Vault has been storing energy since July 2020 by lifting and lowering 35-metric-ton blocks using a specialized tower system. However, these technologies are still not fully ready for widespread commercialization (Figure 2.18).

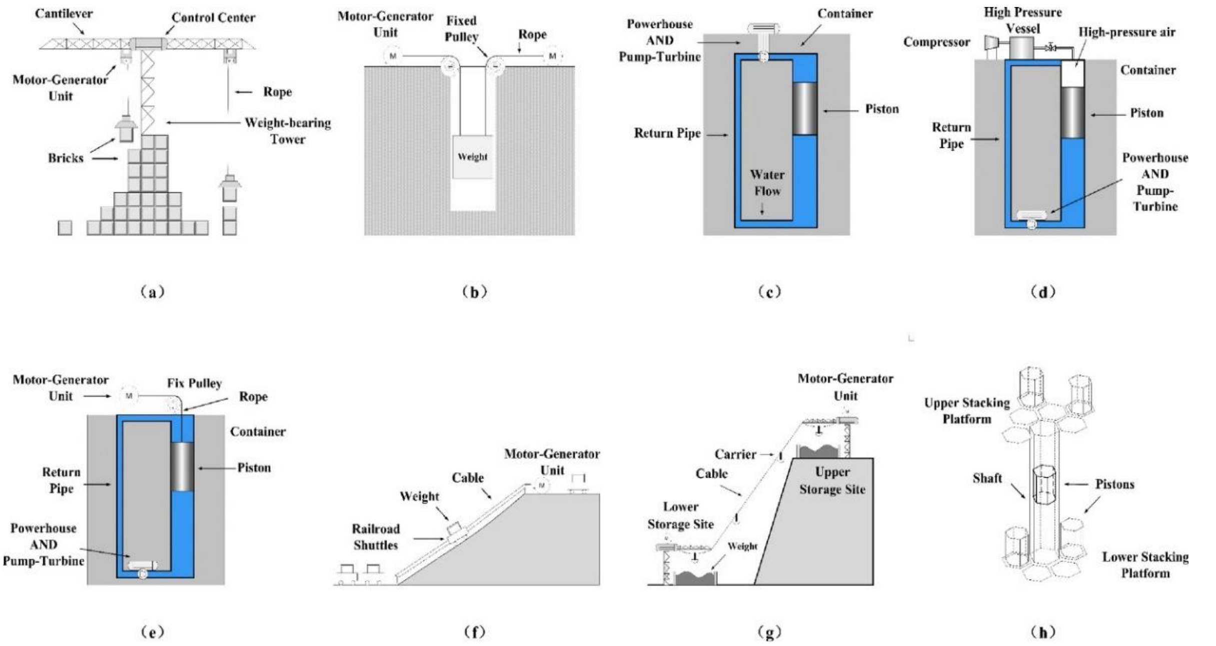


Figure 2.18: Classification of SGES technologies (Source: Tong, 2022)

2.4.14 Advances in Equipment and Monitoring tool

Table 2.4 summarizes some developments in PSP equipment and monitoring tools. Furthermore, a number of additional novel ideas regarding PSP have also been put up by different organizations and scholars; some noteworthy ideas are;

Table 2.4: Advances in equipment and monitoring tools for PSP development

Technology Indicators	Estimated Technology Readiness Level (TRL 1 to 9)
A. Advanced monitoring equipment for wear and tear and maintenance[6]	TRL – 6 to 8
(i) Edge computing sensor for real time monitoring. (ii) Novel digital tools for plant digitalization. (iii) Cavitation and harsh operating condition sensor. (iv) Virtual sensors for runner stress. (v) Cost effective turbidity sensor. (vi) New predictive maintenance algorithm	
B. Improved PSP equipment for salt water Environment[4]	TRL – 5 to 7
(i) Optimized coatings for corrosion and antifouling. (ii) Best tools for bio fouling removal.	
C. Modernization and improvement of existing PSP [4]	TRL – 6 to 8
(i) Control of the MIV for power regulation and transient. (ii) Optimization algorithm for innovative pumping scheme.	
D. Leveraging hybridisation for unconventional storage schemes[4]	TRL – 6 to 8
(i) Development of BESS sizing for hybrid PSP. (ii) Optimized management tool for unconventional hybrid storage scheme. (iii) Advanced controller for fast development services accounting for asset degradation.	
E. Operational tools for control and maintenance (Real time outputs and Simulations.[4]	TRL – 6 to 8
(i) 1D Plant model for PSP operating with dense fluids in coal mine environments. (ii) Optimized controller of PSP for wear and tear reduction. (iii) Cyber-physical platform for Advanced Decision Support (CADS)	

1. Hybrid modular closed-loop scalable PSP - by Aarhus University researchers in Denmark; (https://stateofgreen.com/en/news/water-balloon-tech/)
2. Pressurized vessel PSP – (Chen et al., 2019 ; Koritarov et al., 2022)
3. Geomechanical PSP – by Quidnet Energy, Inc. (https://www.quidnetenergy.com/solution/#technologySection)
4. High-density fluid PSP – developed by RheEnergise, Ltd. (https://www.rheenergise.com/)
5. Thermal underground PSP; proposed by Professors Georg Pikl, Wolfgang Richter, and Gerald Zenz of Graz University of Technology in Austria (Pikl et al., 2017, 2019).

2.5 ANALYZING SPECIFIC INNOVATIVE PSP TECHNOLOGIES IN COMPARISON

PSP has been developed in several regions globally over the years. More recently, significant efforts have been undertaken to develop new technical principles for PSP, several of which have been presented in the preceding sections. Although each of these novel PSP technologies has the potential to enhance the power system, their specific impact will vary depending on

[6] ETIP Hydropower (2024) Innovative Storage Technology and Operations in Hydropower Webinar "Boosting Hydropower: Best Practices for Research" with SHERPA, RevHydro, and STOR-HY, December 2024.

installed capacity, storage capacity, operational characteristics, integration with renewable energy sources, plant location, and other site-specific factors.

To facilitate a comparative evaluation of these innovative PSP technologies, Koritarov et al. (2022) utilized a comprehensive set of evaluation criteria. These include estimated project cost, Levelized Cost of Storage (LCOS), construction time, development risk, scalability and applicability, operational flexibility, potential market size, environmental impacts, physical siting limitations, and Technology Readiness Level (TRL). Table 2.5 presents the findings of this evaluation, highlighting the salient features and comparative advantages of each cutting-edge PSP technology (Source: Koritarov et al., 2022).

Table 2.5: Comparative evaluation of selective innovative PSP technologies
(Source; Koritarov et al., 2022**)**

PSP Technology	Estimated Unit/Plant Size (MW)	Estimated LCOS ($/MWh)	Estimated Gestation period* (yrs)	Estimated Technology Readiness Level (TRLs 1 to 9)
Small PSP with reservoirs of corrugated steel and floating membranes	Unit: 0.5 -5 Plant: 1 - 10	246 –338	2	Overall TRL is estimated to be 4–5. For a project that may use steel tanks for both reservoirs a higher TRL of 6 – 7 is estimated
PSP using submersible pump-turbines and motor-generators	Unit: 1 - 100 Plant: 10 - 200	156 –174	3	For submersible motor-generator a TRL of 9 is estimated whereas, TRL for pump-turbine geometry is 3. Overall estimated TRL is 4–5.
Converting Abandoned Underground mine into PSP	Unit: 10 - 50 Plant: 20 - 100	162 –201	4	TRL estimated is 6
Abandoned Open-pit mine PSP	Unit: 100 - 300 Plant: 20 - 100	193	3	TRL estimated is 8 - 9
Hybrid PSP and wind plant	Unit: 2 - 4 Plant: 8 - 32	151 - 208	3	TRL estimated is 7 - 8
Integrated PSP and desalination plant	Unit: 50 - 150 Plant: 8 - 32	100 - 500	3	TRL estimated is 7
Underground PSP using tunnel-boring machines for storage excavation	Unit: 100 - 300 Plant: 500 – 1,000	210 - 230	5	TRL estimated is 6
Gravity energy storage (see table 2)	5-200 MW		3	TRL estimated is 3 to 7

*added by researchers

The techno-economic viability of Pumped Storage Hydropower (PSP) projects can be further enhanced by emerging technologies, such as the Deep-Sea PSP System, Solid Gravity Energy Storage (SGES), PSP integrated with floating photovoltaic (FPV) systems, and hybrid configurations that incorporate multiple systems, including battery storage. Although many of these technological concepts are still in the early stages of development, they offer significant potential for the future of energy storage. Further operational experience and comprehensive techno-economic viability studies will be necessary to firmly establish the Technology Readiness Level (TRL) and other performance characteristics of these innovative PSP solutions.

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CHAPTER 3: GLOBAL PUMPED STORAGE HYDROPOWER DEVELOPMENT

3.1 OVERVIEW

During the late 20th century, large utility-scale energy storage development accelerated in several regions, including the USA, Japan, Europe, and China, primarily to complement impending major nuclear and coal-fired generating plants. In addition to serving as an energy storage reserve for these large units during forced outages, PSP became essential for load following and utilizing excess electricity generated during nighttime hours. Consequently, these PSP facilities operated on a diurnal cycle, adding to the electricity supply during daily peak periods and utilizing surplus power for pumping at night.

A broad downturn in PSP development occurred during the 1990s. The primary cause of this reduction was a lack of suitable remaining locations for development, coupled with rising awareness of sustainability and environmental protection issues (Nikolaos et al., 2023; Deane et al., 2010). This decline also coincided with a slowdown in nuclear power expansion, as the majority of cost-effective and viable PSP sites had already been developed.

However, starting in 2000, PSP regained significant attention due to the growing demand for renewable energy sources—specifically wind and solar power—and the deregulation of electricity markets in many nations. As a result, Europe and numerous other countries initiated a vast number of PSP projects (Rehman et al., 2015; Deane et al., 2010; Zakeri, 2015). Supporting the rapid integration of intermittent renewable energy into the electricity mix has been the primary driver for this expansion. Combining flexible PSP with wind and solar generation provides an effective means of balancing the grid and transmission networks during both peak and off-peak load periods. Additionally, the global push to reduce fossil fuel dependency in favor of renewable energy has necessitated the rapid deployment of significant energy storage capacity (Koritarov et al., 2022; Kumcu and Wahidi, 2019; Hino and Lejeune, 2012).

3.2 CURRENT GLOBAL PSP STATUS

According to the International Hydropower Association's (IHA) 2025 report, there are over 400 PSP projects currently in operation globally, with an installed capacity of approximately 200 GW. However, synthesized online global data from various sources indicates approximately 343 operational PSP projects with a total capacity of 178 GW. Furthermore, about 197 projects are currently in various stages of development, which are expected to add a total capacity of 360 GW[7]. Further, according to the International Hydropower Association (IHA) PSP projects around the world are estimated to store up to 9,000 GWh of electricity. According to the 2024 World Hydropower Outlook, 214 GW of pumped storage hydropower projects are presently in various phases of development. Recent atlases compiled by the Australian National University identify 600,000 identified off-river sites suggesting almost limitless potential for scaling up global PSP capacity.

7 https://www.hydropower.org/region-profiles/east-asia-and-pacific

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It accounts for over 90% of all long-duration energy storage worldwide[8,9] Further, according to the International Hydropower Association (IHA) PSP projects around the world are estimated to store up to 9,000 GWh of electricity [10]. According to the 2024 World Hydropower Outlook, 214 GW of pumped storage hydropower projects are presently in various phases of development. Recent atlases compiled by the Australian National University identify 600,000 identified off-river sites suggesting almost limitless potential for scaling up global PSP capacity[11].

Table 3.1: Country wise Total number of Pumped storage Hydropower projects with Total installed Capacity

S. No	Country	No of projects			Total Installed Capacity (MW)			Remarks
		Operational	Announced	De-commi-ssioned	Operational	Announced/construction	De-commiss-ioned	
1	China	50	26		53,000	89,000		Status. IHA, 2025[a], IWP, 2024; GESDB, 2020
2	United States	39[R]	67[c]		22,170	50,000		NHA, 2024[c R] Offline/ under Repare – 1 [c] Contracted – 2 Status 2023/ GESDB, 2020
3	Japan	41	1	1	21,817	400	30	Status 2024[8]/ GESDB, 2020
4	Germany	29			9,379			Offline/ under repair – 1 Status 2023/ GESDB, 2020
5	Italy	18	1[c]		7,156	572		[c] Contracted – 1 Status 2023/ GESDB, 2020
6	France	10		1	5,812		82	Status 2023/ GESDB, 2020
7	Spain	22			5,650			Status 2023/ GESDB, 2020
8	India	10	187		6,685.60	1,42,300		Under Construction – 11; Under Operatin - 10 Under various stages of development – 176 As on October 2025 (CEA, 2025)
9	Korea, South	7			4,700			Status 2024[9]
10	Portugal	12			3,585			Status 2023[12]
11	Switzerland	17			3,493			Status 2023[14]

[8] https://www.hydropower.org/publications/enabling-new-pumped-storage-hydropower

[9] https://www.hydropower.org/news/chinas-fengning-station-worlds-largest-pumped-hydro-power-plant-sets-new-global-benchmark#:~:text=Corporation%20of%20China)-,China%20has%20set%20a%20new%20global%20benchmark%20in%20the%20global,integrated%20into%20the%20Fengning%20station.

[10] https://www.hydropower.org/factsheets/pumped-storage

[11] https://www.hydropower.org/factsheets/pumped-storage

S. No	Country	No of projects			Total Installed Capacity (MW)			Remarks
		Operational	Announced	De-commi-ssioned	Operational	Announced/construction	De-commiss-ioned	
12	Austria	18			3,485			Status 2023/ GESDB, 2020
13	Ukraine	3			3,173			Status 2024[15]
14	South Africa	3			2,912			Status 2023/ GESDB, 2020
15	UK	4			2,833			Status 2023/ GESDB, 2020
16	Taiwan	2			2,608			Status 2020
17	Australia	6	1		2,462	250		Status 2023/ GESDB, 2020
18	Thailand	3			1,531			Status 2023/ GESDB, 2020
19	Norway	4			1,441			Status 2023/ GESDB, 2020
20	Poland	6			1,433			Status 2023[11]
21	Russia	5			1,385			Status 2023/ GESDB, 2020
22	Luxembourg	1			1,330			Status 2023[10]
23	Belgium	2			1,307			Status 2023[1]
24	Czech Republic	3	1		1,145	650		GESDB, 2020/ Status 2024[4]
25	Bulgaria	3	2		1,052	1,600		Status 2024[2]
26	Iran	1			1,040			Status 2023
27	Slovakia	4			1,017			GESDB, 2020
28	Argentina	2			974			Status 2023
29	Lithuania	1			900			GESDB, 2020
30	Philippines	1			735			Status 2023/ GESDB, 2020
31	Greece	2	2		699	730		Status 2024[5]
32	Serbia	1			614			Status 2023
33	Denmark	1			600			GESDB, 2020
34	Morocco	1	1		465	350		Status 2023/ GESDB, 2020
35	Bosnia and Herzegovina	1			420			Status 2023
36	Israel	1	1		300	344		Status 2023[7]
37	Ireland	1	1		292	1.50*		Under construction - 1
38	Croatia	3	1		282	498		Status 2024[3]
39	Iraq	1			240			Status 2023/ GESDB, 2020
40	Slovenia	1			185			GESDB, 2020
41	Canada	1	3		177	4,475		Status 2023/ GESDB, 2020
42	Romania	1			92			Status 2023[13]
43	Sweden				91			Status 2023
44	Brazil	1			20			Status 2023/ GESDB, 2020
45	Chile	0	1		0	300		Status 2023
46	Indonesia	0	1		0	943		Status 2024[6]
	Total	343	197	2	1,77,687.6	3,60,082	112	

Data source for Table 3.1 & Figure 3.1:

The PSP Data up to 2023 is extracted from https://www.hydropower.org/region-profiles/east-asia-and-pacific and GESDB (Global Earth System Data Bank) (2020) Sandia National Laboratories Corporation. https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/11/ GES DB_Projects_11_17_2020.xlsx
CEA (2024c) Status of pumped storage development in India up to Oct. 2025 https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf

CEA (2025d) https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf

Other sources for PSP data;

([a]) https://www.hydropower.org/blog/pumped-storage-hydropower-series-chinas-psh-plus-model#:~:text=As%20part%20of%20its%20central,and%20120%20GW%20by%202030.
([c]) https://www.nha2024pshreport.com/nha-psh-2024/
([1]) - https://www.statista.com/statistics/866778/pure-pumped-storage-capacity-in-belgium/
([2]) - https://www.eib.org/en/press/all/2024-201-bulgaria-to-get-energy-boost-with-eib-nek-deal-on-new-hydropower-plants
([3]) - https://balkangreenenergynews.com/croatias-hep-preparing-to-build-pumped-storage-hydropower-plant-blaca/
([4]) - https://www.cez.cz/en/energy-generation/hydroelectric-power-plants/cez-hydroelectric-power-plants/czech-republic/dlouhe-strane
([5]) - https://balkangreenenergynews.com/greeces-ppc-boosts-pumped-storage-hydropower-project-pipeline-to-1-6-gw/
([6]) - https://projects.worldbank.org/en/projects-operations/procurement-detail/OP00299956
([7]) - https://www.gem.wiki/Kokhav_Hayarden_hydroelectric_plant
([8]) - https://www.statista.com/statistics/689667/pumped-storage-hydropower-capacity-worldwide-by-country/
([9]) - https://www.andritz.com/hydro-en/hydronews/hydro-news-asia/south-korea
([10]) - https://www.statista.com/statistics/864376/total-hydropower-capacity-in-luxembourg/
([11]) - https://www.eurasiareview.com/18092023-hydropower-sector-in-poland-historical-development-and-current-status/
([12]) - https://www.ren.pt/en-gb/media/news/electricity-generation-from-pumped-storage-dams-sets-new-record
([13]) - https://balkangreenenergynews.com/romanias-biggest-pumped-storage-hydropower-project-awaits-feasibility-study/
([14]) - https://www.bfe.admin.ch/bfe/en/home/supply/renewable-energy/hydropower/large-scale-hydropower.html
([15]) – Partly damaged due to ongoing war, no clear information is available, https://www.energycharter.org/fileadmin/DocumentsMedia/Occasional/2023_03_28_UA_sectoral_evaluation_and_damage_assessment_Version_VIII.pdf

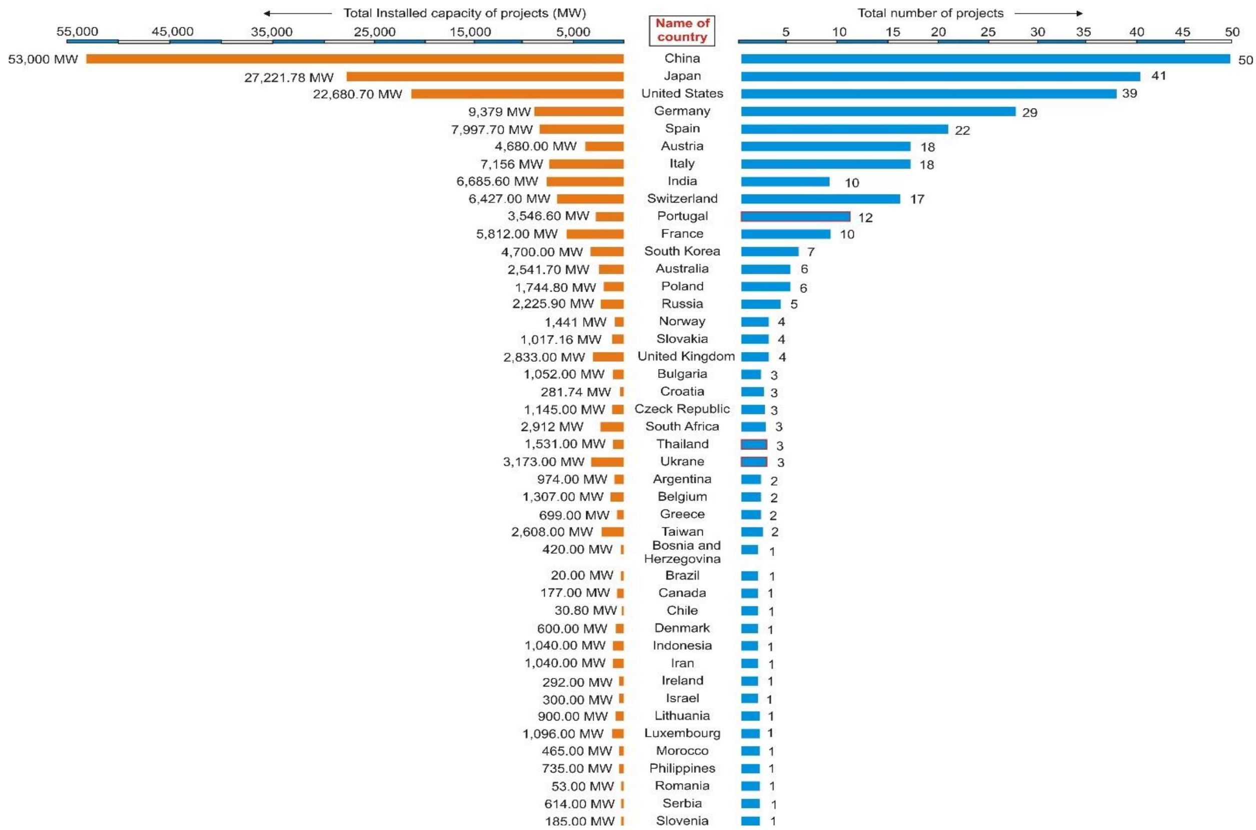

Figure 3.1: Country wise Total number of PSP projects with Total Installed Capacity
(Source: The data source is given inTaab;e 3.1).

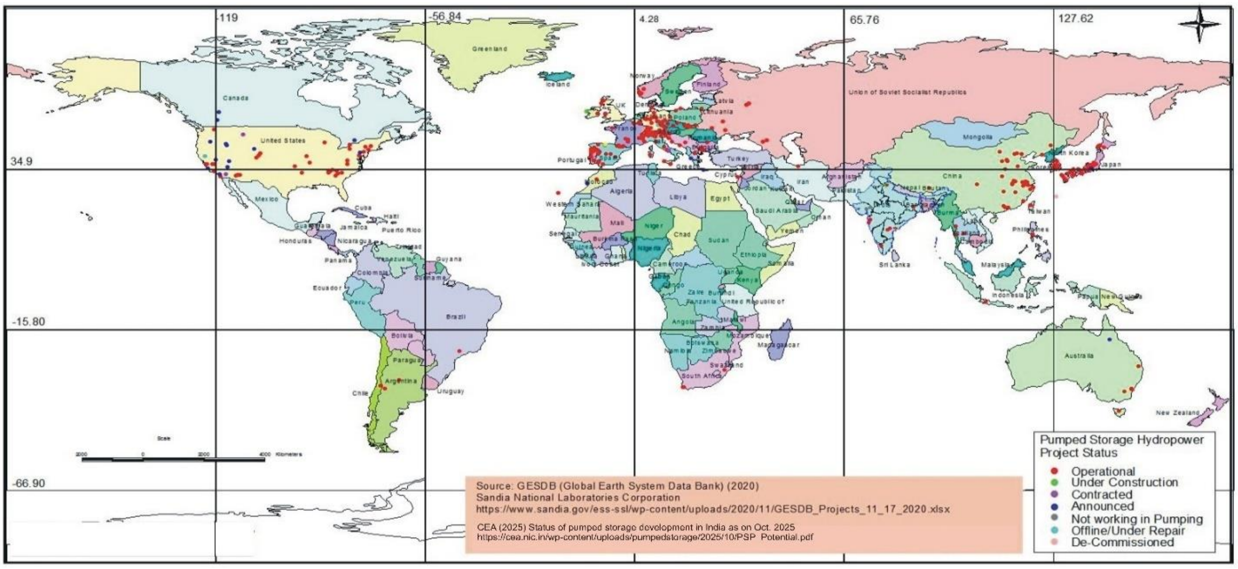

Figure 3.2: Global status and distribution of PSP projects

China and Japan currently hold the majority of PSP capacity in Asia, with Europe and North America following in second and third place, respectively. The development of new PSP capacity has accelerated recently, with China and India leading the global expansion, followed by Europe. For instance, China aims to have 660 GW of total hydropower operational by 2050, which could consist of 150 GW of pumped storage and 510 GW of conventional hydropower (Hydropower and Dams, World Atlas, 2022).

A comparison of nations reveals that China has the highest number of PSP plants at 50, followed by Japan (41), the United States (39), Germany (29), and Spain (22) (Table 3.1). In terms of installed capacity, China leads with 53 GW, while the United States holds 22 GW and Japan holds 21.8 GW (IHA, 2025a; CEA, 2025d; GESDB, 2020). Furthermore, China remains at the forefront of global hydropower development, having installed 6.7 GW of capacity in 2023 alone, of which over 6.2 GW was PSP. This is part of China's broader objective to increase its PSP capacity to 80 GW by 2027[12].

Given the rapid growth of wind and solar PV generation—potentially contributing 50% to 100% of the energy mix—the stability of electric grid systems will depend on a combination of long-distance high-voltage transmission, demand management, and local PSP (Blakers and Stocks, 2017; Lu et al., 2017). Through Geographic Information System (GIS) analysis, Stocks et al. (2019) identified approximately 616,000 potentially viable off-river PSP sites worldwide, with an estimated total storage potential of roughly 23 million GWh. This potential is estimated to be over 100 times the capacity required to support a 100% renewable global electricity system.

India is currently ranked eighth globally in PSP status, with an installed capacity of 6,685.60 MW. However, the Sardar Sarovar PSP (1,200 MW) and Kadana PSP (240 MW) are currently

[12] https://www.hydropower.org/region-profiles/east-asia-and-pacific

not operating in pumping mode (CEA, Status as of Oct. 2025)[13]. Five projects—Turga (1,000 MW), Upper Indravati (600 MW), Kandhaura (1,680 MW), Shirwata (1,800 MW), and Pane (1,500 MW)—have been concurred but are yet to begin construction (CEA, status as on Oct. 2025) [14]. Presently, 11 pumped storage projects (above 25 MW) totaling 12,110 MW are under construction (CEA, Status as on Oct. 2025)[15]. According to the CEA, India is set to become one of the top nations for PSP in the near future, with 197 projects currently operational or in various stages of planning, development, and construction, collectively totaling an installed capacity of approximately 224 GW [16].

3.3 PSP DEVELOPMENT DRIVERS IN DIFFERENT COUNTRIES

Key factors influencing PSP growth in various countries are listed below.

3.3.1 China

Since 2010, China has been actively expanding its PSP capacity to meet increasing power demand and enhance its energy mix. As of 2025, over 26 PSP projects totaling more than 89 GW are under construction, with an additional 30 PSPs—representing 42 GW of installed capacity—scheduled for future development.

The following factors have fueled the growth of PSP projects in China:

- **(i) Government Policy:** Strong central backing for peak demand fulfillment and the integration of renewable energy into the national grid.
- **(ii) Financial Incentives:** The Chinese government provides low-interest loans, tax advantages, and subsidies to stimulate development. This is complemented by the opportunity to participate in ancillary service markets, allowing PSP plants to generate revenue by providing grid stability services.
- **(iii) Regional Energy Support:** Government support for wind energy in Northern and Western China, where transmission infrastructure is relatively inadequate, necessitates local storage solutions (Ming and Daoxin, 2013).
- **(iv) Regulatory Efficiency:** Simplified permitting procedures and clear, standardized guidelines for project development.
- **(v) Market Participation:** Increased participation in electricity markets to optimize operational value (China Energy Portal, 2021).
- **(vi) Grid Integration:** The seamless technical integration of PSP facilities with the national power grid.
- **(vii) High-Proportion Renewables:** China's commitment to supporting the large-scale development of a high proportion of new energy sources through the strategic use of PSP.To achieve these goals, China is embracing cutting-edge technology, superior management practices, and rigorous global standards in its PSP development.

[13] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_In_Operation.pdf

[14] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSPs_concurred.pdf

[15] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Under_Construction.pdf

[16] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf

3.3.2 USA

At the end of 2023, the United States had 102,120 MW of installed hydroelectric capacity. Total hydropower generation reached 240 TWh, while the installed capacity for pumped storage was 22.17 GW. Although PSP plants are instrumental in integrating renewable energy into the U.S. grid, their share of deployed utility-scale energy storage dropped sharply from 93% in 2019 to 70% in 2022. This decline in the PSP market share is primarily explained by the extremely rapid growth of battery installations during 2021 and 2022. By the end of 2020, utility-scale battery capacity in the United States had reached 1.52 GW. With new battery installations contributing 3.4 GW in 2021 and 4.1 GW in 2022, the total utility-scale battery capacity reached 9 GW by the end of 2022 (USDE, 2023).

The continued interest in PSP development is driven by its potential to supplement the growing renewable energy supply and provide crucial capacity, flexibility, grid stability, and long-duration (8–12 hours) energy storage. Furthermore, the United States has established goals to achieve a 100% clean energy economy by 2050 and a PSP capacity of 30 GW by 2030. In early 2024, Rye Development announced that it had been selected by the Department of Energy (DOE) to receive US$81 million for the Lewis Ridge PSP project. This funding was provided through the DOE's Clean Energy Demonstration Program on Current and Former Mine Land, supported by the Bipartisan Infrastructure Law (BIL)[17].

3.3.3 Japan

Japan is focused on improving grid stability and optimizing its energy infrastructure, with PSP serving as an indispensable element. With more than 40 PSP plants in operation and over 21.8 GW of capacity, Japan has a long history of utilizing PSP technology and is currently the third largest country in the world in terms of installed PSP capacity (JEPIC, 2024). The nation is a global leader in PSP technology, demonstrated by facilities such as the Okinawa Yanbaru Seawater Pumped Storage Power Station—a pioneering facility that utilized seawater for energy storage.

Regarding new projects and construction, Japan continues to fund the development of new PSP facilities to further enhance its energy infrastructure. One such undertaking is the Kannagawa Hydropower Plant (KHP) in Nagano, Japan, which has been partially operational as of February 2024. With a planned 2.6 GW capacity, this project will rank among the largest PSP plants globally. Furthermore, the Japanese government is actively seeking collaborations and funding to identify additional potential PSP sites across the nation.

The expansion of the PSP sector in Japan has been driven by several key factors:

- **Policy Support:** The government is dedicated to enhancing the country's energy infrastructure through targeted PSP project development.
- **Favorable Geography:** Japan possesses abundant water resources, including numerous rivers and lakes. Additionally, the country's mountainous landscape provides the ideal topography for high-head PSP projects.

[17] https://www.hydropower.org/region-profiles/east-asia-and-pacific

- **Economic Demand:** Japan's advanced economy requires a steady and dependable electricity supply to maintain industrial stability.
- **Financial Incentives:** The Japanese government offers various financial incentives, including tax rebates, feed-in tariffs, and subsidies, to encourage PSP development.
- **Decarbonization Goals:** The 2050 carbon neutrality target provides a significant push for expanded energy storage.
- **Capacity Targets:** The government has established a specific goal to develop an additional 10 GW of PSP capacity.
- **Renewable Energy Mix:** Japan is committed to generating 36–38% of its electricity from renewable sources by 2030, with hydropower specifically targeted to contribute 9.6%.

3.3.4 Spain

In 2023, Spain has 20,425 MW of installed hydropower capacity and 5,650 MW of installed PSP capacity. A total of 25 TWh[18] was generated by hydropower. Additionally, six PSP projects totaling 2.5GW of installed capacity and more than 740 GWh of energy storage are either in the permitting stage or in the building phase[19] as of 2024.

The following factors are the primary drivers of PSP development in Spain:

- **Legislative Mandates:** Spain enacted a pioneering climate change law—the first of its kind globally—that requires all businesses to implement explicit climate strategies. This law includes emission reduction goals that must be met over five-year periods and designates the development of PSP projects as a top priority.
- **Strategic Funding:** As part of an ambitious plan to establish 22 GW of storage capacity by 2030, the Spanish government has allocated €100 million specifically for the development of PSP plants.
- **System Flexibility and Stability:** To enhance grid flexibility, the government is encouraging the advancement of energy storage technologies integrated with renewable sources. This strategy accounts for both large-scale and distributed storage, aiming for a total capacity of approximately 20 GW by 2030 and 30 GW by 2050.

3.3.5 Germany

In Germany 9,379 MW of PSP installed capacity existed as of 2023[20]. According to the *Hydropower and Dams World Atlas (2022)*, pumped storage plants generated 5.3 TWh of electricity while consuming 7.2 TWh for pumping operations. Several significant projects are currently advancing the sector. The Gaildorf Project, a hybrid PSP and wind facility developed by Max Bögl Wind AG in Baden-Württemberg, is scheduled for commissioning in 2025. Voith is supplying three 6.1 MW variable-speed pump-turbines for this project. Additionally, in January 2024, EnBW commenced construction of a new PSP station at Forbach in the southern state of Baden-Württemberg. EnBW plans to invest approximately €280 million to transform the 71 MW Rudolf-Fettweis-Werk (RFW) conventional

[18] https://www.hydropower.org/region-profiles/europe
[19] https://www.hydropower.org/region-profiles/europe
[20] https://www.hydropower.org/region-profiles/europe

hydropower complex into a modern pumped storage facility (Hydropower & Dams, 2024). By 2030, the capacity of pumped storage hydropower plants in the German energy system is anticipated to increase by approximately 1.4 GW.

The following factors are the primary drivers of PSP growth in Germany:

- **(i) Renewable Energy Targets:** Under the German Government's plan and the Renewable Energy Act (EEG), at least 80% of the gross power consumption must come from renewable sources by 2030, with a goal of achieving a greenhouse gas-neutral power system following the coal phase-out. This transition necessitates expanded PSP and storage capacity to provide essential grid flexibility.
- **(ii) National Storage Strategy:** In December 2023, the German Federal Ministry for Economic Affairs and Climate Action (BMWK) unveiled a comprehensive electricity storage strategy. This approach aims to facilitate sector growth and achieve optimal integration between the power system and storage assets.
- **(iii) Innovation Tenders:** To encourage the construction of additional energy storage, "innovation tenders" have been established with larger bidding volumes. Furthermore, green hydrogen tenders are being launched for the first time. Approximately 800 MW were scheduled for auction in 2023, followed by 200 MW per year until 2026 (Hydropower and Dams, World Atlas, 2022).

3.3.6 France

In 2023, France's installed capacity for pumped storage was 5,812 MW[21]. The French government has been supporting a dedicated PSP program since 2022 through extensive consultations. Consequently, there are encouraging initial indications of PSP policy development at the national level. National officials are increasingly focused on enhancing pumped storage hydropower potential through policy and regulatory advancements as wind and solar contributions continue to rise[22].

The 10-year energy strategy adopted in 2020 calls for a significant increase in renewable energy capacity. The *Programmation Pluriannuelle de l'Énergie* (PPE) aligns with the National Low-Carbon Strategy (SNBC), which establishes a roadmap for carbon neutrality by 2050 and lays out energy industry goals for the 2019–2023 and 2024–2028 periods. Under this 10-year plan, renewable generating capacity is anticipated to reach between 100 and 113 GW by 2028—accounting for up to 36% of total power production. Following the previous PPE's goal of adding 1 to 2 GW of pumped storage between 2025 and 2030, EDF announced a new storage plan in 2018. This plan targets more than 10 GW of new storage by 2035, including provisions for up to 2 GW of new pumped storage and 1 GW of conventional storage (Hydropower and Dams, World Atlas, 2022).

The following primary drivers for the growth of PSP in France are evident:

[21] https://www.hydropower.org/region-profiles/europe
[22] https://www.hydropower.org/region-profiles/europe

(i) **Nuclear Integration:** The French PSP fleet was extensively developed between the 1970s and 1990s to coincide with the expansion of nuclear power plants. Reversible Francis pump-turbines with high unit outputs (>200 MW) were installed to manage grid stability. Because traditional nuclear plants lack operational flexibility [2], robust storage compensation from PSP was necessary to balance nuclear generation between peak and off-peak demand periods.

(ii) **Government Policy Support:** Active government backing continues to promote the strategic development of PSP.

(iii) **Renewable Energy Targets:** Large-scale energy storage is recognized as a fundamental requirement to achieve the nation's renewable energy integration targets.

3.3.7 Switzerland

As of 2023, Switzerland's total pumped storage hydropower capacity was 3,493 MW[23],[24]. According to the International Hydropower Association (IHA, 2024), the Swiss government shortlisted 16 PSP projects between 2020 and 2021 as part of a multi-stakeholder engagement aimed at creating 2 TWh of storage capacity over two decades. Additionally, a new regulation was passed by the Swiss government in 2023 to streamline approval procedures for renewable energy initiatives, specifically aimed at accelerating the development of PSP projects[25].

The Swiss government's Energy Strategy 2050 prioritizes a reduction in energy consumption alongside the increased utilization of hydropower and other renewable resources, such as solar and wind. By 2035, generation from new renewable sources is anticipated to reach 11,940 GWh. Under this plan, Switzerland’s five operational nuclear reactors will be retired at the end of their lifespans, and no new nuclear facilities will be constructed. Furthermore, the Swiss Federal Council aims to reduce the country's average per capita energy usage by 35% compared to 2000 levels by 2035. Given that PSP offers both long-duration energy storage and the technical advantages of a machine-based interface for grid stability, it remains a cornerstone of the government's energy policy.

3.3.8 Australia

Approximately two-thirds of Australia's electricity demand is currently met by coal-fired power plants, according to Blakers and Stocks (2017). However, by 2030, three-quarters of these plants will be over 40 years old, necessitating their replacement with modern energy sources. Australia is aggressively expanding its wind and solar photovoltaic (PV) capacity; with an annual growth rate of approximately 1 to 2 GW, it is anticipated that renewable sources will provide 50% of Australia's electricity by 2030.

Due to the rapid expansion of variable wind and solar PV power, large-scale energy storage will be essential for grid balancing. According to the Australian Renewable Energy Agency (ARENA): "We have identified that PHES [PSP] will play a significant role in helping Australia transition to renewable energy, and will continue to provide funding support and

[23] https://www.premel.ch/IT/Hydroelectric-Power-In-Switzerland-Status-and-Overview-for-2023-bd071c00
[24] https://www.bfe.admin.ch/bfe/en/home/supply/renewable-energy/hydropower/large-scale-hydropower.html
[25] https://www.hydropower.org/region-profiles/europe

guidance to assist with development and financing." This institutional support, combined with favorable government policies, serves as the primary driver for PSP growth in Australia[26].

Overall there were 2,461 MW[27] of installed pumped storage capacity. Several major PSP projects are currently under construction or in development, including the significant Snowy 2.0 expansion. The 250 MW Kidston PSP in Queensland is currently under construction and is anticipated to be commissioned in 2024. Notably, this is the world's first project to co-locate a PSP facility with a solar farm.

Other major initiatives include the 600 MW Oven Mountain PSP, which is currently under investigation. Additionally, EnergyAustralia and Arup Group have proposed the Cultana PSP near Port Augusta in South Australia. This project has a planned capacity of 225 MW and is designed to utilize seawater for energy storage (Hydropower and Dams, World Atlas, 2022). Furthermore, the Pioneer-Burdekin PSP project, announced in September 2022, is part of what is expected to be the largest PSP scheme in the world. Stage one of this project is projected to provide 5 GW of storage near Queensland's mid-coast, with the final stage expected to be operational by 2035[28].

3.3.9 Conclusion

The discussion of the factors driving Pumped Storage Hydropower (PSP) development across various countries leads to the following conclusions:

(i) **Strategic Decarbonization:** As major nations worldwide increase their share of variable renewable generation and work toward net-zero targets, they are actively investing in PSP alongside other energy storage technologies, such as battery storage, to ensure grid reliability.

(ii) **Necessity of Government Support:** Robust government backing is essential for the continuous expansion of PSP. Nearly every nation reviewed has implemented financial incentives, enabling legislation, and various policy frameworks to promote and accelerate PSP development.

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[26] https://arena.gov.au/renewable-energy/pumped-hydro-energy-storage/
[27] https://www.hydropower.org/region-profiles/east-asia-and-pacific
[28] https://www.hydropower.org/region-profiles/east-asia-and-pacific

CHAPTER 4: MARKET STRUCTURE, POLICIES AND BUSINESS MODELS FOR PSP IN DIFFERENT COUNTRIES

4.1 OVERVIEW

The International Energy Agency (IEA) predicts that, alongside batteries, pumped storage hydropower (PSH) will remain a primary source of electricity storage capacity. By 2030, new projects are expected to boost global pumped storage capacity by 7%, reaching a total of 9 TWh. Although battery storage capacity (including electric vehicles) is projected to increase more than tenfold by 2030, the total capacity of pumped storage will still significantly exceed that of batteries. Furthermore, adding pumping capabilities to existing hydropower facilities is expected to provide an additional 3.3 TWh of storage capacity, supplementing future greenfield pumped storage projects[29].

4.2 CHALLENGES IN PSP DEVELOPMENT

In general, global PSP development faces several significant challenges, including:

- **(i) Environmental and Social Impact:** The requirement for two distinct reservoirs (upper and lower) can result in a significant amount of land being submerged. Beyond potentially degrading local ecosystems, this can impact communities living within the proposed reservoir regions. Consequently, obtaining building permits and licenses can be a lengthy process, particularly for on-river PSP projects.
- **(ii) High Capital Investment:** One of the primary challenges for PSP development is the exorbitant cost associated with constructing two reservoirs, installing specialized pump-turbines, and developing the necessary infrastructure.
- **(iii) Siting and Geological Constraints:** Identifying topographically and geologically suitable locations for water retention can be difficult, especially in flat regions or areas with complex geological terrains.

Nevertheless, many countries are actively developing policies, regulatory frameworks, and innovative business models to encourage PSP development. This progress is driven by the critical role that pumped storage plays in successfully integrating renewable energy into modern electricity grids. The following section discusses the specifics of several leading countries with significant installed and planned PSP capacities.

4.3 MARKET FOR PSP IN CHINA

From 2021 to 2035, the National Energy Administration (NEA) of China implemented a long-term and mid-term plan for PSP development. Through this ambitious strategy, China aims to increase its installed PSP capacity to at least 62 GW by the end of 2025, 80 GW by 2027, and up to 120 GW by 2030. As of 2025, China maintains more operational PSP capacity than any other nation, with over 53 GW currently in service—accounting for approximately 27% of the global total. With an additional 80 GW of capacity either under construction or scheduled for development by 2027[30], China's PSP

[29] https://www.iea.org/reports/hydropower-special-market-report/executive-summary
[30] https://www.hydropower.org/region-profiles/east-asia-and-pacific

capacity is projected to expand significantly (IWP, 2024; https://www.hydropower.org/region-profiles/east-asia-and-pacific; USEIA, 2023)

The two-part tariff methodology for Pumped Storage Hydropower (PSP) has been further enhanced by the National Development and Reform Commission (NDRC) of the People's Republic of China. In May 2023, the NDRC introduced a comprehensive reform of the electricity pricing structure, which includes both energy and capacity price components.

- **Energy Price:** This is a volume-based price determined by market transactions. It reflects the value provided by the PSP plant in offering peak shaving services to the grid.
- **Capacity Price:** This fixed price is designed to recover the investment costs associated with fixed assets. It reflects the value of the PSP station in providing essential ancillary services, such as black start capabilities, frequency management, voltage support, and system backup.

To ensure sustainable profitability, PSP stations utilize the capacity charge to recoup fixed costs that exceed those covered by daily pumping and generating operations. Under this new pricing structure, the PSP capacity price and ancillary service expenses are accounted for separately from transmission and distribution tariffs. For both new and existing PSP facilities, capacity prices typically range between 289 and 722 RMB/kW. This enhanced NDRC pricing structure serves as a significant policy driver for the continued expansion and financial viability of the PSP sector in China (Peng et al., 2023).

4.3.1 Regulations and Policies that Support PSP in China

China has implemented several policies beneficial to the PSP market, including:

(i) **Financial Incentives:** Low-interest loans, tax advantages, and government subsidies are utilized to stimulate investment in PSP projects. The Chinese government offers direct incentives to developers to help offset high upfront capital expenditures. These subsidies can cover a significant portion of the total project investment, making PSP projects more financially viable.

(ii) **Tax Benefits:** PSP projects in China qualify for various tax breaks, such as reduced corporate income tax rates, Value-Added Tax (VAT) refunds or exemptions, and preferential treatment regarding land use and property taxes. These advantages enhance the overall economic viability of PSP initiatives.

(iii) **Regulatory Efficiency:** Implementation of simplified permitting procedures and unambiguous development guidelines to streamline project lifecycles.

(iv) **Ancillary Service Markets:** Authorization for PSP plants to participate in ancillary service markets, allowing them to generate revenue by providing essential grid stability services.

(v) **Environmental Integration:** Strategic balancing of PSP development with environmental considerations, including ecological impact assessments and sustainable water resource management.

(vi) **Grid Connectivity:** Ensuring that PSP plants can seamlessly connect to the national grid and participate actively in electricity markets.

(vii) **Provincial Strategies:** Provincial governments have established specific plans and incentives for regional PSP implementation, tailored to local grid conditions, renewable energy targets, and resource availability. For instance, provinces like Yunnan and Sichuan—which possess abundant hydropower resources—have prioritized large-scale PSP projects to facilitate the integration of renewable energy and enhance regional grid stability (Papadakis et al., 2023).

(viii) **Market Diversification:** Encouragement of diversified ownership and private sector participation to foster a more competitive and dynamic PSP market (China Energy Portal, 2021).

4.3.2 Business Models for PSP in China

(A) Government support model

(i) Generation-Based Feed-in Tariff (FiT)

1. **Eligibility:** PSP projects operated by grid operators or Independent Power Producers (IPPs) are eligible for the generation-based tariff mechanism.
2. **Incentive Structure:** This method incentivizes project owners to maximize electricity production to increase total revenue.

(ii) Two-Part Tariff

1. **Structure:** This model consists of a variable generation-based tariff and a fixed annual capacity-based payment.
2. **Capacity Payment:** According to Kumar et al. (2023), the capacity payment is designed to cover the majority of fixed expenses, associated taxes, and a risk-adjusted return rate. This rate is typically 1% to 3% higher than the risk-free rate (the interest rate on long-term government bonds).
3. **Ancillary Services:** The approval process for capacity tariffs has been enhanced to compensate for essential ancillary services, including frequency regulation, voltage control, system backup, and black start capabilities (Nibbi et al., 2021).
4. **Regulatory Framework (China):** China's National Development and Reform Commission (NDRC) has implemented regulations to bolster the PSP capacity market. To ensure balanced cash flow throughout a specified 40-year operational term, the capacity tariff must cover all costs while providing reasonable profit margins for the plant.
5. **Generation Tariff:** The generation tariff is intended to compensate for variable operational expenses, such as pumping costs and generation losses. According to Kumar et al. (2023), the pumping cost is typically approximately 75% of the benchmark electricity price for local coal-fired power.

(B) Capacity based Lease Arrangements

1. Under the facility rental model, project owners receive a fixed annual payment from the grid provider to lease the facility. This payment is designed to cover all project expenses—excluding power costs for pumping operations—as well as applicable taxes, yielding a rate of return of approximately 5%.
2. Because the payment amount is independent of the actual quantity of electricity generated or market price fluctuations, the grid operator can dispatch the pumped storage station strategically to maximize overall system benefits. This ensures that the facility is utilized for optimal grid stability and peak shaving without financial risk to the project owner (Kumar et al., 2023).

(C) Market-Driven Model

This approach generates revenue by capitalizing on current electricity market dynamics. PSP plants engage in the day-ahead market by purchasing electricity during low-demand periods and reselling it when demand peaks. Although China has established a spot market for electricity, it is still in the developmental stages[31]; it is anticipated that PSP facilities will increasingly participate in this market in the future. A mature electricity market should provide the necessary framework to guide PSP plants in adapting their operations and generating income flexibly (Tian et al., 2023).

Furthermore, the introduction of market mechanisms for frequency regulation auxiliary services across 13 Chinese provinces and regions in June 2022 provides an additional revenue stream for PSP (Huang and Li, 2023). In this specific market, the allowable bidding range is set between a minimum price of 0.1 RMB/MW and a maximum price of 100 RMB/MW.

4.4 MARKET FOR PSP IN JAPAN

4.4.1 Regulations and Policies that Support PSP in Japan

The following regulations and policies are formulated by the Japanese Government:

(i) **Comprehensive Market Regulation:** The Japanese government has developed a comprehensive set of rules and policies to regulate the nation's hydropower market, giving top priority to the efficient operation, environmental preservation, and sustainable growth of hydropower projects[32]. As a crucial facilitator of the shift to renewable energy, PSP has continuously received funding from the Japanese government. It views PSP as an essential technology for incorporating variable renewable energy sources into the grid and has stated aspirations to create 10 GW of PSP capacity.

(ii) **Exploration and Innovation:** To find additional possible PSP locations across the nation, the Japanese government is aggressively seeking collaborations and funding. The "Innovative Technology Strategy for Energy Conservation" is one of the programs

31 https://dialogue.earth/en/business/the-current-state-of-chinas-electricity-market/
32 https://www.meti.go.jp/english/policy/index.html#ep

that Japan's Ministry of Economy, Trade, and Industry (METI) has started to encourage the study and advancement of cutting-edge energy storage technologies (Papadakis et al., 2023). Japan's commitment to utilizing its PSP potential is exemplified by local references such as the Okinawa Yanbaru Seawater Pumped Storage Power Station and the soon-to-be-built Kannagawa Hydropower Plant (World Atlas, Hydropower and Dams, 2022).

4.4.2 Business Models for PSP in Japan

In 2016, the Japanese electricity market was fully liberalized. The Japan Electric Power Exchange (JEPX) serves as the market platform, while the grid consists of ten regional Transmission System Operators (TSOs). These TSOs exercise authority over their respective regional networks, managing power producers and suppliers (PPS), demand analysis, and power retailing. Currently, Japan operates an energy market for day-ahead and real-time transactions, alongside a capacity market for long-term capacity procurement. The various components of the Japanese power market are depicted in Figure 19. Additionally, in 2024, Japan intends to launch a market for day-ahead and week-ahead supplementary services, which will provide PSP facilities with further revenue-generating opportunities[33].

In addition to JEPX, the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) serves as an independent system operator (ISO) responsible for maintaining the supply-and-demand equilibrium across regions. OCCTO has implemented a priority dispatch mechanism to guarantee this balance (Figure 4.1). Every electric power company adheres to these priority dispatch criteria to maintain grid stability. This regulation establishes the terms, prerequisites, and sequence of curtailment for various electricity production sources in response to demand variations.

An overview of the priority dispatch rule is provided in Figure 4.2. Under these rules, the output of thermal power plants is decreased and/or PSP facilities initiate pumping operations in the region before the output of renewable energy sources, such as solar PV, is curtailed (Ichimura, 2020).

In January 2024, OCCTO held its second "Long-term Decarbonization Power Source Auction," the results of which were revealed on April 30th. A total of 1.67 GW of projects were awarded contracts, including 32 battery energy storage systems (BESS) totaling 1.1 GW and three pumped hydro energy storage (PHES) projects totaling 577 MW.

Based on the explanation provided above, there are significant opportunities for new PSP and other energy storage technologies to generate income within the power market. While the government may offer further assistance through tax incentives and subsidies, the exact scale and duration of such support remain undefined.

4.5 MARKET FOR PSP IN USA

A $71.5 million fund has been released by the Department of Energy (DOE) to enhance projects selected by the Grid Deployment Office under the Hydroelectric Efficiency Improvement

33 https://www.forbes.com/sites/woodmackenzie/2024/03/12/ancillary-services-market-redesign-to-drive-grid-scale-battery-uptake/

Incentive program. According to ETN News (Feb. 6, 2024), these projects are expected to leverage $468 million in combined federal and private investment, ultimately strengthening the hydropower sector. By the end of 2022, there were 96 PSP projects with a total power storage capacity of 91 GW in the U.S. development pipeline. However, despite these ongoing initiatives, the United States remains one of the few regions globally with no major PSP projects currently under construction.

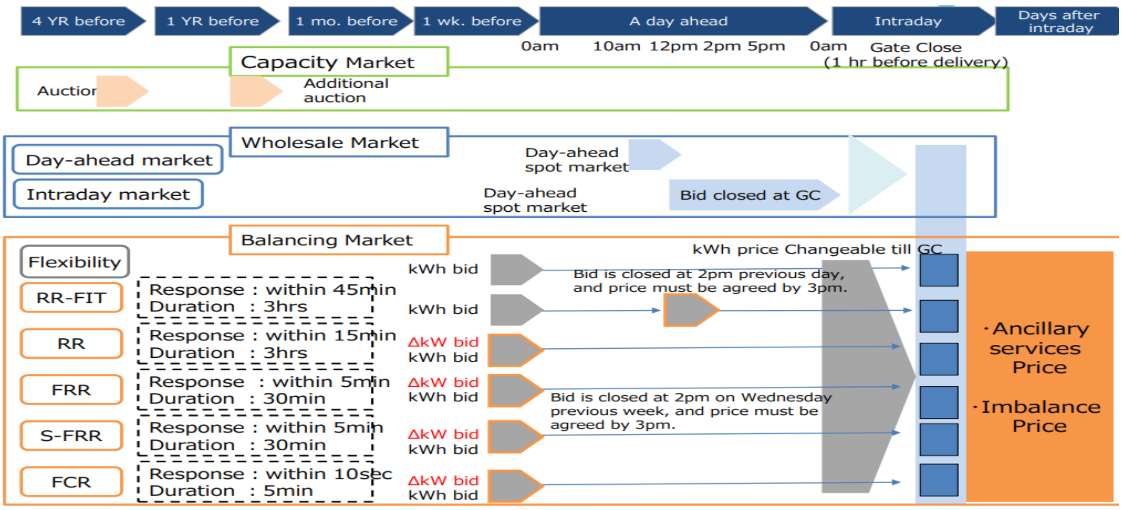


Figure 4.1: Components of Japan's electricity market (Source: MEITI, Japan, 2021[34])

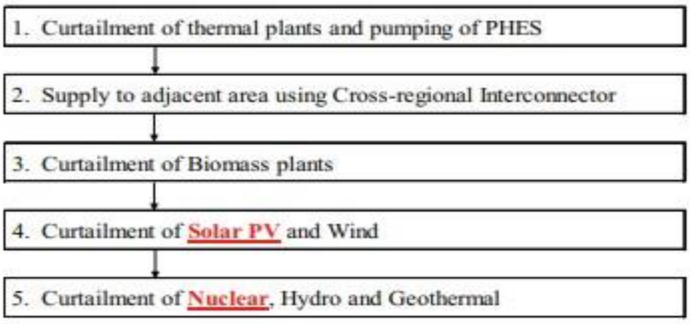


Figure 4.2 Summary of the order of priority dispatch rule in Japan (Source: Ichimura, 2020)

4.5.1 Regulations and Policies that Support PSP in USA

Numerous federal, state, and municipal entities are involved in the intricate regulatory framework for PSP in the United States. Among the important regulations are:

(i) Federal power Act: All PSP projects that use federal lands or waters must be licensed by FERC, under this act. The development and management of hydroelectric projects, including PSP facilities, are governed by this commission. They guarantee that these initiatives adhere to safety and environmental regulations. The three main parts of the Commission's hydropower program are licensing, administration and compliance, and

34 https://www.openadr.org/assets/210422_DER_METI_Mr.%20SAKUMA.pdf

dam safety and inspection. With an installed capacity of more than 16,500 MW, the Commission has approved a total of PSP that are built and operating. Over 30 years have passed since the majority of these projects were approved[35].

(ii) Endangered Species Act : According to this act, PSP initiatives must not damage threatened or endangered species.

(iii) Clean Water Act: In order to release water into surface waters, PSP projects must seek permissions under this act.

(iv) State-Level Regulations: Each state has its own laws pertaining to construction, environmental preservation, and water use.

At the same time, the federal government has implemented a number of initiatives to assist the growth of PSP plants. These consist of:

(i) Federal Investment Tax Credit (ITC): This tax credit offers a 30% deduction for new PSP projects' capital expenses[36].

(ii) New grid-scale storage projects should become more competitive as a result of the August 2022 Inflation Reduction Act's inclusion of an investment tax credit for stand-alone storage[37].

(iii) Hydropower Production Tax Credit (PTC): This tax credit is given for electricity produced by PSP projects. In the US, the PTC is a federal tax credit that encourages the generation of electricity from hydropower and other renewable energy sources. It offers a credit for each kWh of power produced by qualified projects[38].

Table 7 highlights the details of tax credits available at the federal level for PSP development.

4.5.2 Business Models for PSP in USA

About 60% of energy is traded in organized markets[39] in the United States, which includes a mix of deregulated and vertically integrated utilities. Generation, transmission, and distribution are all owned and run by vertically integrated utilities. One such instance is the approximately 1,500 MW Castaic Pumped Storage Plant, which is owned by the Los Angeles Department of Water and Power, the biggest municipal utility[40] in the US. However, California ISO, often known as CAISO, is a sizable structured market that covers the majority of the state. Table 4.1 presents Summary of Federal Tax Credits for Hydropower in USA.

The complex structure of the power market supports a variety of business strategies for PSP development. Vertically integrated utilities can either develop their own PSP projects—passing the costs to captive customers through retail rates—or sign a Power Purchase Agreement (PPA) with a third-party developer and rate-base those costs. An illustration of this utility-led approach is the 25-year PPA signed by the Los Angeles Department of Water and Power (LADWP) for 400 MW of solar and 800 MWh of energy storage in California's Central Valley.

35 https://www.ferc.gov/industries-data
36 https://www.energy.gov/eere/water/inflation-reduction-act-tax-credit-opportunities-hydropower-and-marine-energy
37 https://www.iea.org/energy-system/electricity/grid-scale-storage
38 https://www.energy.gov/eere/water/inflation-reduction-act-tax-credit-opportunities-hydropower-and-marine-energy
39 https://www.justice.gov/atr/media/1347641/dl?inline
40 https://www.ladwp.com/who-we-are

However, because no new PSP facilities have been constructed recently, specific data regarding PPA pricing for pumped storage remains unavailable.

An alternative business strategy is predicated on the arbitrage principle within organized electricity markets. This allows energy to be purchased during low-demand periods and sold when demand peaks, enabling pumped storage facilities to generate revenue by capitalizing on price differentials.

Despite the potential for profit, these organized markets make it challenging to forecast long-term costs and revenues for PSP plants, introducing significant uncertainty regarding future prices for capacity, energy, and grid services. To mitigate this risk, certain markets, such as CAISO or PJM, have established mechanisms to reimburse resources for their specific capacity contributions to the grid.

Table 4.1: Summary of Federal Tax Credits for Hydropower in USA

Internal Revenue Code Section	Name	Summary
45	Production Tax Credit (PTC)	\$5.50/megawatt-hour + additional credit of \$22.00/megawatt-hour if labor standards are met* for specific renewable technologies. Available for projects beginning construction before 2025.
45Y	Clean Electricity PTC	Similar value as 45 PTC credit, for zero- or negative-emitting technologies. Phases out when power sector emissions reach 25% of 2022 levels. Available for projects placed in service in 2025 and later.
48	Investment Tax Credit (ITC)	6% credit + additional credit of 24% if labor standards are met* for specific energy and storage technologies. Available for projects beginning construction before 2025.
48E	Clean Electricity ITC	6% credit + additional 24% if labor standards are met for zero- or negative-emitting technologies and energy storage technologies. Phases out when power sector emissions reach 25% of 2022 levels. Available for projects placed in service in 2025 and later.
Cross-cutting Provisions	Prevailing Wage and Apprenticeship Standards*	To receive the enhanced tax credit, projects must meet prevailing wage and apprenticeship requirements for construction, alteration, or repair.
	Energy Community Bonus	10% increase in the PTC or up to 10 percentage points increase in the ITC if projects are located in an “energy community.”
	Domestic Content Bonus	10% increase in the PTC or up to 10 percentage points increase in the ITC if domestic content requirements are met.
	Elective Pay (sometimes known as direct pay) and Transferability	Tax-exempt entities, states and political subdivisions thereof, the Tennessee Valley Authority, Indian tribal governments, Alaska Native Corporations, and rural electric co-ops can make an election to treat the credit as a payment against tax and potentially get a refund. Taxpayers ineligible for elective pay can elect to transfer credits to other taxpayers.

In California, Load-Serving Entities (LSEs) are subject to annual and monthly system-level and local-level resource adequacy criteria set by the California Public Utilities Commission (CPUC). This framework is similar to the requirements for DISCOMs in India. When an LSE enters into a contract with a generating resource to satisfy its resource adequacy needs, the resource is compensated based on market-based pricing.

The average cost of local resource adequacy for capacity contracts signed between 2021 and 2023 for the 2022 compliance year was $7.70/kW-month, while the average cost of system-level resource adequacy was $7.68/kW-month[41]. Energy storage assets, such as battery storage, can contribute to resource adequacy provided they can maintain their rated output for at least four hours[42]. No specific duration requirement of this nature was identified for PSP.

In a similar vein, PJM—the largest organized power market and grid operator in the United States—responded to FERC Order 841 by allowing energy storage, including PSP, to provide energy, capacity, and ancillary services. Unlike conventional generation resources, energy storage technologies do not require a unit commitment, assuming there are no start-up or load expenses. However, for capacity payments, PJM only compensates power levels that can be maintained for at least ten hours. Under this rule, a 100 MW, 4-hour energy storage system would be downgraded to 25 MW for capacity valuation. Given their typically long storage durations, PSP facilities may be particularly advantageous under these market conditions.

4.6 MARKET FOR PSP IN FRANCE

In 2023, France's installed PSP capacity reached 5,812 MW (IHA, 2024). Since 2022, the French government has been actively promoting PSP through extensive multi-stakeholder consultations. Consequently, encouraging frameworks for national-level PSP policy development have been established to support the sector's growth.

4.6.1 Regulations and Policies that Support PSP in France

In France, the development of Pumped Storage Hydropower (PSP) has been uneven across mainland regions and non-interconnected zones (NIZ). Growth has historically been higher in NIZ regions due to specific power network requirements and physical conditions. In these areas, storage capabilities have been developed through two primary pathways:

- **(i)** **Centralized Processes:** Storage projects can receive either (a) reimbursement for public electricity service charges if they reduce overall production costs, or (b) distributions from the Electricity Equalization Fund if they reduce network expenses. Both pathways are subject to review by the French Energy Regulatory Commission (CRE).
- **(ii)** **Decentralized Processes:** Operators of hybrid production facilities—which combine solar PV or wind generation with storage capacity—can profit from Power Purchase Agreements (PPAs) following a competitive call for bids or based on a tariff order.

[41] https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/resource-adequacy-homepage/2022-ra-report_05022024.pdf
[42] https://www.caiso.com/documents/2023-special-report-on-battery-storage-jul-16-2024.pdf

On the French mainland, there is no specialized support program dedicated specifically to storage. Instead, development is characterized by two distinct regulatory environments:

(i) **Pumped Storage Power Plants (PSP):** These are governed by the standard framework for hydroelectric facilities. Depending on their size, they are either authorized or subject to a concession agreement (for capacities exceeding 4,500 kW). Although PSP is an established technology, its advancement is often hindered by lengthy construction timelines and procedural restrictions. Under the current Multiannual Energy Plan (PPE), the government aims to develop 1.5 GW of new PSP capacity between 2030 and 2035.

(ii) **Market-Based Storage Technologies:** Technologies examined by the CRE in 2019 are not intended to receive special government assistance, as they are considered competitive endeavors. Instead, they are expected to utilize existing market mechanisms. To facilitate this, the CRE has encouraged transmission and distribution system operators to publish data regarding network congestion and flexibility requirements. Furthermore, the CRE recommended that RTE (the transmission operator) modify market access rules—particularly for long-term capacity tenders—to enable more effective participation from storage devices[43].

Additionally, under **Article L. 211-2-1 of the Energy Code**, energy storage projects within the electrical system are classified as being of **overriding public interest**, provided they meet specific decree requirements. This classification is intended to streamline the issuance of the licenses and permits necessary for project execution.

4.6.2 Business Models for PSP in France

(1) Government Support

The French government may issue tenders to acquire necessary storage capacity. For example, on June 12, 2019, the Ministry of Ecological Transition (MTE) launched the storage-focused long-term call for tenders (AOLT). This tender was open to all carbon-neutral technologies and was organized by the transmission system operator, Réseau de Transport d'Électricité (RTE), in accordance with the French capacity mechanism.

The primary goal of the AOLT was to enable the development of new capacities to ensure long-term security of supply. Successful bidders were granted guaranteed prices under the capacity mechanism[44], providing revenue stability for seven-year periods beginning in 2020, 2021, 2022, and 2023, respectively. While this tender resulted in the procurement of 377 MW of total storage capacity, it is important to note that none of the selected projects were PSP facilities[45].

(2) Electricity Market

Since 2017, the French Transmission System Operator (RTE) has participated in the Frequency Containment Reserve (FCR) Cooperation platform. This initiative facilitates the sharing of

[43] https://www.whitecase.com/insight-alert/electricity-storage-france-new-calls-tenders-will-be-launched
44 https://iclg.com/practice-areas/renewable-energy-laws-and-regulations/france
45 https://www.whitecase.com/insight-alert/electricity-storage-france-new-calls-tenders-will-be-launched

FCR capacity across neighboring European nations. Under this framework, electricity generation is adjusted (increased or decreased) symmetrically to maintain grid stability. Since July 2020, the regulations require that FCR capacity be reserved in four-hour blocks. Market participants are compensated based on the auction's marginal price, while FCR energy activation is settled on a prorated basis. Notably, unlike other participating nations, RTE remunerates FCR energy based on day-ahead pricing: participants receive the day-ahead price for upward activations and pay it for downward activations (RTE 2020a).

In France, any generator with a nominal capacity exceeding 120 MW is legally mandated to provide automatic Frequency Restoration Reserve (aFRR) capacity. This requirement is symmetric, with the required volume determined by the generator's share of total expected national production (RTE 2020a). Real-time aFRR energy activation is split among suppliers pro-rata to their offered capacity. Activated energy is compensated at the day-ahead price, while aFRR capacity is remunerated at a regulated price of approximately €19/MW/h (RTE 2020a).

Additionally, Manual Frequency Restoration Reserve (mFRR) and Replacement Reserve (RR) capacities are procured through annual and daily auctions, offering various products with different durations (RTE 2020b). The adjustment mechanism activates mFRR and RR energy according to a merit-order of energy bids (RTE 2020c). This method involves energy activation auctions on the day of delivery, requiring generators to offer their full available capacity to the TSO. This allows for "free bids," where participants can submit reserve energy bids without a pre-existing reserve capacity contract. Activated bids are compensated at the specific bidding price submitted (RTE 2020c)[46].

4.7 MARKET FOR PSP IN ITALY

By 2030, the Italian National Integrated Energy and Climate Plan (PNIEC) aims to achieve a total of 8 GW of pumped storage hydropower (PSP) capacity. Energy storage through PSP is widely recognized as essential for facilitating the nation's transition to a low-carbon economy by integrating increasing shares of renewable energy. Italy already possesses a significant amount of PSP capacity—approximately 4.3 GW as of 2024—which provides a strong foundation for reaching the 8 GW target by the end of the decade. Consequently, Italy is positioned to become a European leader in the deployment and operation of advanced PSP technology[47].

4.7.1 Regulations and Policies That Support PSP in Italy

Italy is implementing a €17.7 billion state aid package to establish a centralized electricity storage system. Over the next 10 years, developers of qualified projects will receive annual compensation covering both their capital investments and operational expenses. The European Commission authorized this €17.7 billion plan in accordance with EU state aid regulations to assist Italy in developing a centralized power storage framework. By enabling the integration

46 https://ideas.repec.org/a/fan/efeefe/vhtml10.3280-efe2023-002004.html
47 https://www.trade.gov/market-intelligence/italy-energy-storage

of variable renewable energy sources, this initiative will help achieve the objectives of the Fit-for-55 package and the European Green Deal.

Under this system, the Italian government will select companies developing energy storage projects that meet specific eligibility criteria for subsidies. The program is designed to support electricity storage facilities with a combined operating power of 9 GW and a total energy capacity of 71 GWh through the end of 2033. To ensure transparency and fairness, Italy is required to use a competitive, non-discriminatory bidding process to select beneficiaries. Developers will compete based on bids requesting the lowest amount of aid per unit of offered capacity.

This scheme is open to any technology that satisfies the performance standards established by Terna, the national Transmission System Operator (TSO), and approved by relevant authorities. To account for technological advancements, the list of eligible technologies will be updated every two years. Currently, the qualified technologies include Pumped Storage Hydropower (PSP) and electrochemical lithium-ion battery systems[48].

4.7.2 Business Models for PSP in Italy

Italy is implementing a novel policy approach for the design of its power market. This aims to help the energy transition by offering long-term investment signals through mechanisms on top of the spot market. Three pillars support the strategy[49]:

The Capacity Market to ensure overall security of supply;

(i) Capacity payment awarded (#/MW premium).
(ii) Long term price signals for flexible capacity.
(iii) BESS eligible, but the longer period is now overvalued and the shorter duration is impacted by strong derating factors
(iv) The limitation of excessive price levels as a result of power market price caps.

The novel "DM FER X" RES CfD (contract for difference) mechanism to encourage sporadic RES investment;

(i) Creative CfD using a payment approach for perceived electricity generation.
(ii) Long term price signals for intermittent RES.
(iii) Auction structure driving optimal location
(iv) Redefination of risk allocation between the system and RES producer
(v) CfD can be hybrid with merchant/ PPA model
(vi) Maintains some short-term RES profile optimization price signals

To encourage storage investment, the Electricity Storage Capacity Procurement Mechanism (MACSE) focuses on longer periods.

(i) Long duration value is taken into account (#/MWh)

48 https://balkangreenenergynews.com/italy-to-subsidize-centralized-energy-storage-system-projects-with-eur-17-7-billion/
49 https://timera-energy.com/blog/italy-rolls-out-new-model-for-bess-investment/

(ii) Long term price signals for electricity storage capacity buildout.
(iii) Cap & floor MSD prices and strong competitive pressure on MSD
(iv) Inflation indexed
(v) Cap & floor MSD prices and strong competitive pressure on MSD

In order to enable decarbonization with intermittent renewables, ensure system adequacy, and ensure adequate electricity storage capacity to support decarbonization[50], each of these techniques has different but complimentary goals. Along with other long-term compensation systems like the Capacity Market, the electricity storage capacity procurement mechanism conforms to the Italian regulatory framework.

Because market risks, long-term uncertainties, and high investment costs might deter potential investors and make project financing more difficult, **MACSE** is intended for electricity storage as a long-term investment support to overcome uncertainties. Given the anticipated high penetration of intermittent solar capacity, it acknowledges the critical role that **BESS** and Pumped Hydro Storage (**PHS**) will play in Italy's energy future. With premiums, MACSE will offer a consistent revenue stream. It is focused on storage systems (lithium-ion batteries and pumped storage hydropower facilities) and is drawing interest even from overseas. It is the first long-term compensation through competitive auctions.

This method is in line with the Italian regulatory framework, which already has or plans to implement other long-term compensation mechanisms, including the capacity market and renewable energy auctions (MACSE, 2024). Additionally, operators who have authorizations to build and run new storage systems, have never taken part in the capacity market or the Fast Reserve pilot project before, and have given up all other incentives are eligible to participate. Having a hydroelectric concession is required for pumped-storage facilities. Projects that upgrade existing hydroelectric plants or turn them into pumped-storage facilities are also eligible, as long as the increase equals at least 15% of the maximum energy storable before the improvement. Only the incremental capacity is eligible to participate in the mechanism in such circumstances.

There will be several auctions for each competitive bidding procedure, each of which will correlate to a certain set of reference technologies. There will be two auctions in the initial bidding process: The short-term auction, which is based on lithium-ion battery technology, awards contracts with a two-year planning horizon and a fifteen-year delivery timeframe. The long-term auction is based on pumped-storage hydroelectric technology and awards contracts with a 30-year delivery period and a 6-year planning horizon (MACSE, 2024).

Standard supply contracts are given to the auction winners, giving them the right to receive from Terna the monthly premium determined during the auction and valued in accordance with the pay-as-bid criterion—that is, the amount offered. Consequently, the premium obtained is unaffected by performance coefficients. In return, the grantees agree to participate in the Ancillary Services Market under regulation and make the contracted storage capacity available for the delivery of time-shifting items (MACSE, 2024).

50 https://timera-energy.com/blog/italy-rolls-out-new-model-for-bess-investment/

According to the mechanism's design specifications, the fixed premium established through competitive procedures during the auction serves as the main source of income for the storage system operator. However, the storage system will have the option to offer and keep 20% of the profits made in the Ancillary Services Market in order to guarantee the effective functioning of the system in supplying services to the grid. In order to prevent the recurrence of a variable penalty, these offers must also comply with the regulations, which essentially direct them to provide the full capacity at competitive pricing.

If the offered price is higher (lower) than a strike-price for upward (downward) balancing bids, the market operator must pay a variable penalty. The downward strike-price is fixed at €0/MW, while the upward strike-price is determined using the most recent technique authorized by the Regulatory Authority for Energy, Networks, and Environment (ARERA) for determining the strike-price utilized in the Capacity Market.

4.8 MARKET FOR PSP IN AUSTRALIA

By accelerating pre-commercial innovation, the Australian government is supporting the global shift toward net-zero emissions through the Australian Renewable Energy Agency (ARENA). ARENA achieves this by mobilizing capital, expertise, and stakeholders to foster energy innovations that underpin Australia's renewable energy ecosystem. Recognizing that Pumped Storage Hydropower (PSP) is vital to the nation's energy transition, ARENA continues to provide financial support and strategic advice to facilitate the development and funding of PSP projects.

The demand for PSP has been further driven by Australia's rapidly expanding wind and solar portfolios. The primary goal of PSP development is to ensure a stable power supply and provide essential grid balancing services. A landmark in this effort is the Kidston PSP project—the first new PSP system in Australia in 37 years—which reached financial close in 2021 with significant federal backing. This project underscores the government's commitment to fostering the growth of the sector. According to the Australian Energy Market Operator (AEMO), the nation will require 15 GW of utility-scale storage by the early 2040s. PSP offers a versatile and powerful method for managing electricity supply and demand, ensuring grid resilience as coal-fired generation retires[51].

4.8.1 Regulations and Policies that Support PSP in Australia

The Renewable Energy Target (RET) was a significant policy initiative by the Australian Government designed to incentivize the production and utilization of renewable energy sources. By establishing a market for renewable energy certificates, the RET encouraged the construction of new renewable energy projects, including PSP facilities.

Originally introduced in 2001 and significantly updated in 2009, the program aimed to generate an additional 33,000 GWh of electricity from renewable sources by 2020. The RET program was underpinned by a system of tradable certificates known as Renewable Energy Certificates

51 https://arena.gov.au/renewable-energy/pumped-hydro-energy-

(RECs). Under this mechanism, accredited renewable energy producers are issued certificates for each MWh of renewable electricity generated[52].

4.8.2 Business Models for PSP in Australia

The evolution of wholesale power prices in Australia is significantly impacting the profitability of renewable energy plants and will likely influence future investment decisions for large-scale renewable projects. There has been a noticeable shift in the intraday pricing of wholesale electricity over the course of a 24-hour period. Primarily due to the increased penetration of solar power, daytime electricity costs have decreased drastically relative to the morning and evening peaks. This "duck curve" effect is most pronounced during the middle of the day when solar output is at its maximum (Figure 4.3). This pricing trend suggests that energy arbitrage—buying low during the day and selling high during peaks—could provide a substantial revenue stream for Pumped Storage Hydropower (PSP) in Australia.

PSP plants may submit offers for the 1 GW of long-duration energy storage that was just put up for auction by the Australian Energy Market Operator. Additionally, $6 billion in investment has been offered by Queensland State in Australia to advance the Borumba Pumped Hydro Project (2000 MW with 24-hour storage[53]). An estimated $14.2 billion[54] will be spent on the project in its entirety.

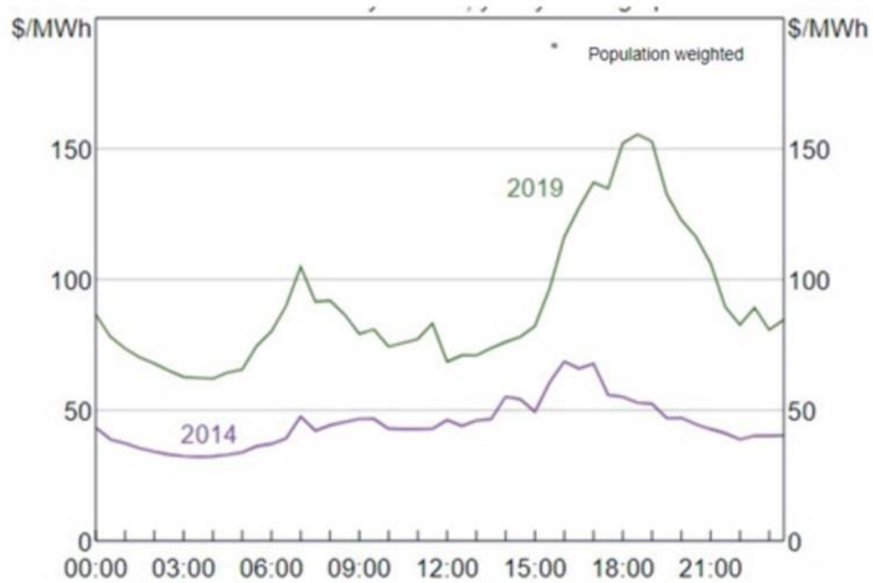


Figure 4.3: Intraday wholesale Electricity Prices in Australia
(Source: ABS, AEMO, RBA)
(National Electricity Marjet (NEM) Yearly Average Price)

52 https://www.dcceew.gov.au/energy/renewable/target-scheme
53 https://qldhydro.com.au/wp-content/uploads/2022/09/QLD-Hydro-Fact-Sheet-Borumba-Project-Overview.pdf
54 https://qldhydro.com.au/projects/borumba/#:~:text=Project%20status&text=In%20June%202023%2C%20the%20Queensland,targeting%20first%20power%20in%202030.

4.9 SUMMARY OF GLOBAL PSP POLICIES, REGULATIONS, AND BUSINESS MODELS

The Summary of global PSP policies, regulations, and business models are given in Table 4.2 and Table 4.3;

Table 4.2: Policy Enabling PSP Development across Geographies

Support Type	China	Japan	USA	France	Italy	Australia
Special focus on PSP development	Yes	Yes	No	No	Yes	Yes
Government Subsidies	yes	Not found	Not found	Yes	Yes	Not found
Tax breaks	yes	Not found	Yes (ITC and PTC)	Not found	Not found	Not found
low-interest loans	yes	Not found	Not found	Not found	Not found	Not found
Any other support	1. Streamlined permitting processes 2. clear guidelines for PSP development 3. Balancing PSP development with environmental considerations	-	Multiple conditional provisions in tax codes (e.g., 105 increase in PTC if domestic content requirements are met)	Protected species exemption under Article L. 211-2-1 of the Energy Code that can designate a storage facility as of overriding public interest	-	Market for Renewable energy certificates

Table 4.3: Business model of PSP Development across Geographies

Support Type	China	Japan	USA	France	Italy	Australia
Long-Term PPA/Government specified Tariff	Yes	Not found	Yes (at State level))	Storage focused long-term call for tenders	Yes	Not found
Wholesale Energy/Spot Market Energy Arbitrage Opportunity	Yes, but evolving	Yes (planning for day-ahead and week-ahead ancillary services market)	Yes	Yes	Yes	yes

Support Type	China	Japan	USA	France	Italy	Australia
Wholesale Capacity Market for valuing capacity		Yes	Yes	Not found	Yes	Not found
Other Mechanism (s)	Capacity based Lease Arrangements Market mechanism for frequency regulation ancillary services launched in 13 provinces and regions of China	Long-term Decarbonisation Power Source Auction	Not found	3. Frequency containment reserve (FCR) Cooperation platform. Remunerates FCR energy to the day-ahead price 4. Automatic frequency restoration reserve (aFRR) capacity remunerated through a regulated price close to 19€/MW/h and the activated energy is paid as per the day-ahead price 5. Manual frequency restoration reserve (mFRR) and Restoration reserve (RR) capacity procurement. Activated bids are paid as per their bidding price	6. Contract for Differences 7. MCASE specifically designed for long duration storage i.e., BESS and PSP	$6 billion investment by the State of Queensland in a PSP project

CHAPTER 5: LEARNINGS AND EXPERIENCE GAINED FROM INTERNATIONAL PSP PROJECTS

5.1 PREAMBLE

A comprehensive evaluation of the literature was conducted as part of the current study to understand successful PSP programs in various countries. A wide range of published and unpublished research articles, technical reports, and web resources were examined. The primary purpose of this review was to identify noteworthy PSP initiatives that are currently operational or underway and performing exceptionally well.

The study focuses on identifying technical specifications, design advancements, and innovations in mechanical, electrical, and civil equipment. Furthermore, the review explores the integration of PSP with other energy sources—specifically variable renewables such as solar and wind—and assesses its contributions to grid flexibility and stability. This section presents the detailed findings regarding the identified PSP projects.

5.2 REVIEW OF SUCCESSFUL INTERNATIONAL PSP PROJECTS

5.2.1 Case Study – 1: Conventional Closed –loop PSP

Table 5.1: Changlongsha PSP Project (2.1 GW), China

S. No	Particulars	Description
1	Case Study	Conventional Close –loop PSP
(i)	Name of PSP Plant	Changlongsha
(ii)	Country	China
(iii)	Status	Operating
(iv)	Date of Commissioning	June, 2022
(v)	Location	Located in the Yu village of Shanchuan township, near Tianhuangping town, approximately 25km away from Anji County, in the Zhejiang province of China.
(vi)	Owner	China Three Gorges
(vii)	Operated by	China Three Gorges
(viii)	Technical Specifications	
	Power capacity	2.1GW (6 x 350 MW)
	Head	710m
	Turbine	Phase IA - Voith Hydro Holding francis turbine, one-unit 350MW. Phase IB - Voith Hydro Holding francis turbine, one-unit 350MW. Phase II - Dongfang Electric francis turbines. 4 turbine units, each with 350MW capacity.
	Generator	Phase I – One-unit electric generator Voith Hydro Holding with capacity 389.9 MVA. Phase IB – One unit electric generator Voith Hydro Holding with capacity 389.9 MVA. Phase II – Four unit electric generator Dongfang Electric with capacity 389.9 MVA[55].

55 https://www.power-technology.com/data-insights/power-plant-profile-changlongshan-china/

S. No	Particulars	Description
	Reservoirs	Reinforced concrete face rockfill dams with maximum dam heights of 103 and 100 meters, respectively, are used to form the upper and lower reservoirs. The upper reservoir's dead water level will be roughly 940 meters, although its typical storage level would be 976 meters. The upper reservoir will have a total storage capacity of 10.99 million cubic meters (mcm), with a normal storage level of 10.44 mcm. The lower reservoir will have a dead water level of 220 meters and a typical storage level of 243 meters. The lower reservoir's typical storage capacity is 14 mcm, while the overall storage capacity is 16.11 mcm. Three 850-meter-long diversion inclined wells with straight sections of 435, 434, and 432 meters each make up the water delivery system.
(ix)	Operational Aspect	The biggest pumped storage power plant in eastern Chin is Changlongshan Hydropower Station. On June 30, 2022, it went into full functioning. The combined capacity of its six 350 MW pumped storage units is 2.1 GW. During peak hours, it adds 2.435 billion kWh of electricity to the system annually on average. China's top-rated head pumping storage power plant is Changlongshan hydropower station. The world's largest pumped storage unit at this capacity level, units 5 and 6, have a rated speed of 600 RPM[56].  **Changlongshan hydropower station in China (2.1 GW)**
(x)	Power evacuation	Two 500kV power transmission lines evacuate the electricity produced by the Changlongshan pumped storage power facility. The transformer tunnel connects the facility to the East China Power Grid[57].
(xi)	Challenges Faced	Numerous difficulties that are typical of large-scale hydropower projects have been encountered by the Changlongshan Pumped Storage Power Station. Here are a few of the noteworthy difficulties: **Equipment Supply and Installation**: The project's partner, Voith Hydro, emphasized the difficulty of providing and setting up the first 600 r/min pumped storage unit in history. This required supplying entire power units and overseeing their integration into the infrastructure of the power plant, which is a significant task. **Seepage Detection**: For the station to operate safely and effectively, the integrity of the tunnels and reservoirs must be maintained. Effective seepage detection surrounding the station is one of the specific technological issues mentioned. To

56 https://news.cgtn.com/news/2022-06-30/Largest-pumped-storage-power-station-in-E-China-put-into-operation-1bidaYOnK9O/index.html
57 https://news.cgtn.com/news/2022-06-30/Largest-pumped-storage-power-station-in-E-China-put-into-operation-1bidaYOnK9O/index.html

S. No	Particulars	Description
		overcome this difficulty and guarantee the stability of the structures, strategies like the resistivity approach have been used.
(xii)	Technological advancement	• Changlongshan PSP has the highest-rated head (710m) . • It has six 350 MW Francis pump turbine with a total capacity of 2.1 GW. • With a capacity of 350 MW and a rated speed of 600 rpm/min, the two Francis pump turbine units (Units 5 and 6) provided by Voith Hydro Holding are the first of their kind in the world for a high-capacity, high-head PSP. (C_817026.htm, https://en.powerchina.cn/2022-09/29)It is adding on an average 2.435 billion kilowatt-hours of electricity to the grid each year during peak hours. • Peak shaving, valley filling, frequency regulation, phase adjustment, system standby, and other services are provided by the facility, which is connected to the East China Power Grid.
(xiii)	Factors that contributed to the success of Changlongshan PSP Plant	• China's strenuous drive to work on a lucid PSP development, particularly with new policies and project goals is an important factor for the successful completion of Changlongshan PSP Plant • Changlongshan PSP Plant has been developed under a highly competitive modern pumped storage industry, and a number of large-scale backbone PSP enterprises cultivated in recent times (China Energy Portal, 2021). • The PSP is providing flexibility and stability to the grid by adding on an average 2.435 billion kilowatt-hours of electricity to two 500kV power transmission lines connected to the East China Power Grid[58]. • The Changlongshan PSP Plant was developed with advanced technology, high-quality management, and international standards to meet the needs of large-scale development of high proportion of new energy. • China Government has provided supportive policies and incentives that includes Govt. subsidies, Tax breaks, low interest loan on investment, streamlined permitting process, seamless connection to grid, participation of PSP in electricity market etc. under such support Changlongshan PSP Plant was developed. • PSP plant participate in day-ahead and intraday markets and it buy electricity during low demand and selling it during peak load times. • The electricity pricing from PSP include; the "two-part tariff" mechanism - energy prices and the capacity prices. Energy price - charged for transaction volume and Capacity price – based on fixed asset • Grid enterprises purchase electricity from the PSP and pay service fees on behalf of the power system and users.

58 https://news.cgtn.com/news/2022-06-30/Largest-pumped-storage-power-station-in-E-China-put-into-operation-1bidaYOnK9O/index.html

S. No	Particulars	Description
(xiv)	Best practices and Lessons	• The PSP project involves innovative modern design that includes highest rated head of 710m. six 350 MW Francis pump turbine with a total capacity of 2.1 GW. • The project has used for the first time in the world 2 Francis pump turbine unit's having rated speed of 600 rpm/min with a high capacity of 350 MW each designed for high rated head equal to 710m[59] .
(xv)	**Recommendations in Indian Context**	• The Changlongshan PSP Plant is a good example that may inspire and give confidence for the planning and development of similar large-scale PSP plants in India because of its size (2.1 GW), high rated head of 710m, installation of six massive Francis pump turbine units, each with a capacity of 350 MW, and management of their integration into the power infrastructure of two 500kV power transmission lines connected to the East China Power Grid. • Finding and developing possible PSP sites that might be accessible with high relative relief in India's Himalayan valleys may be encouraged by the Francis pump turbine's high speed (600 rpm/min) and high rated head (710 m). • The Changlongshan PSP Plant's success serves as a reminder that new PSP projects must embrace cutting-edge technology and adhere to excellent management practices. • It also emphasizes the necessity of encouraging government policies and incentives to promote the growth of PSPs. PSP development in India may be further aided by the availability of subsidies, tax breaks, low interest investment loans, a simplified permitting process, a smooth grid connection, PSP involvement in the electricity market, etc.

5.2.2 Case Study – 2: Conventional Close – loop PSP in High Altitude Freezing Zone

Table 5.2: Hohhot PSP Project (1,224 MW), China

S. No	Particulars	Description
2	Case Study	Conventional Close –loop PSP in High Altitude Freezing Zone
(i)	Name of PSP Plant	Hohhot also known by Huhehaote
(ii)	Country	China
(iii)	Status	Operating
(iv)	Date of Commissioning	2014
(v)	Location	Located 20 km north of Hohhot town in Inner Mongolia, China; Coordinates: 40°59′14″N 111°41′18″E
(vi)	Owner	Inner Mongolia Hohhot Pumped Storage Power Generation Co., Ltd.
(vii)	Operated by	Hohhot Co., Ltd.
(viii)	Technical Specifications	
	Power capacity	1,224MW (Generation) 1,641,000 hp (Pumping)
	Head	Gross head 585m and Net head 521m
	Turbine	Francis pump turbine (4 x 306 MW) DEC Dongfang Electric Machinery and GE Renewable Energy.
	Generator	DEC Dongfang Electric Machinery and GE Renewable Energy

59 https://en.powerchina.cn/2022-09/29/c_817026.htm

S. No	Particulars	Description
	Reservoirs	Upper Reservoir: 62.5 m high concrete face rock fill dam with a 6,660,000 m^3 capacity. volume of 7,170,000 m^3. Two gravity dams made of concrete that has been roller-compacted form the lower reservoir. At 57 meters (187 feet) high, the upstream dam traps sediment in the river that supplies water to the power station.
(ix)	Operational Aspect	• When output is curtailed, the Hohhot PSP plant provides additional power capacity, peak demand power, energy storage for standby emergency power, and frequency regulation.. • Energy storage for emergency power standby, frequency management, supplemental power during periods of lower production, and power for peak demand are all provided by the PSP in addition to wind farm production.[60]. • The operating conditions of the Hohhot PSP are harsh and required a specific design of pump turbines and motor-generators that includes: • Higher stability while operating over a large head range and Ability to withstand load and thermal cycles due to frequent starts and stops • Higher availability to cope with demand from the grid. • The four reversible, 306 MW Francis pump turbines and motor generator units at the PSP plant were provided and installed by GE. • To ensure maintenance free solution the rotor spider ,motor generator's upper bracket, and stator frame were equipped with oblique elements that allow thermal expansion without moving parts. Since this greatly reduces element fatigue and permits smaller clearances, the generators are more compact, efficient and reliable. The maintenance-free oblique elements increase generator lifetime and—given their smaller foundation – decrease construction costs[61].. • The project is provided with a grid regulator for load balancing, frequency modulation, and condensing. It serves as well as an emergency reserve to ensure the safe, economic and stable operation of the power grid[62]..
(x)	Power evacuation	The Hohhot PSP plant is generating on an average approx. 2.007 billion kW annually. The PSP plant is complementing their wind farm production, as well as to provide the electrical network with power for peak demand, supplemental power for periods of reduced production, energy storage for emergency power stand-by and frequency regulation[63].
(xi)	Challenges Faced	• The major challenges during construction and operational phase at Hohhot PSP project were related to the harsh conditions prevailing at the PSP site. The lowest temperature at the project site is -41.8 °C, which makes the freeze-breaking temperature.

60 https://www.ge.com/renewableenergy/stories/hohhot-flexible-storage
61 https://www.gevernova.com/hydropower/stories/hohhot-flexible-storage
62 https://infra.global/projects/hohhot-pumped-storage-power-station/
63 https://www.gevernova.com/hydropower/stories/hohhot-flexible-storage/

S. No	Particulars	Description
		• The mix structure that features the RCC outside and the conventional concrete inside needs special innovative resistant design to avoid frost-and-crack performance of RCC gravity dam. • The civil works and the elecro mechanical equipments (pump-turbine and generator) required innovative design considerations so that it can be designed to meet out anticipated adverse freezing conditions likely to be faced at a lowest temperature of -41.8 °C.  **Hohhot PSP Plant in China (1,224MW)**
(xii)	Technological advancement	• Inovative design as per the harsh conditions prevailing at the PSP site • The lowest temperature at the project site is -41.8 °C, which makes the freeze breaking temperature of panels .The mix structure that features the RCC outside and the conventional concrete inside has greatly improved the frost-and-crack-resistant performance of RCC gravity dam. • New technologies had deployed, including an intelligent spraying cooling system for asphalt concrete panels, an intelligent self-flow water replenishment system for reservoir, full-digital industrial TV system for the power station, and an intelligent integrated control cabinet for GIS equipment. • The project also designed a high-pressure steel bifurcation pipe that boasts an internal water pressure of 9.06 MPa and a HD value of 4140mm, which is the largest made up of high-strength steel of 790 MPa grade[64].. • The motor generator's upper bracket, rotor spider and stator frame were equipped with patented oblique elements that allow thermal expansion without moving parts, resulting in a maintenance free solution. The maintenance-free oblique elements increase generator lifetime and—given their smaller foundation – decrease construction cost.
(xiii)	Factors that contributed to the success of Hohhot PSP Plant	• Hohhot PSP plant was developed with advanced innovative technology so that it can be operated safely under anticipated adverse freezing conditions being faced at a lowest temperature of -41.8 °C. • The PSP project is meeting the needs of high proportion of new energy. approx. 2.007 billion kWh annually.

64 https://infra.global/projects/hohhot-pumped-storage-power-station//

S. No	Particulars	Description
		• The PSP plant is complementing wind farm production, as well as it is supporting grid by providing power for peak demand, supplemental power for periods of reduced production, energy storage for emergency power stand-by and providing frequency regulation[65]. • Hohhot PSP Plant was developed with China Government's supportive policies and incentives that includes Govt. subsidies, Tax breaks, low interest loan on investment, streamlined permitting process, seamless connection to grid, participation of PSP in electricity market etc.
(xiv)	Best practices and Lessons	• The Hohhot PSP plant is located in region where the minimum temperature may reach upto -41.8oC. Thus, the design of civil works and electro mechanical equipments was made and executed with advanced innovative technology so that the plant can be operated safely under anticipated adverse freezing conditions. • The lowest temperature at the project site (-41.8 °C) may result into freeze-breaking of panels .The mix structure that features the RCC outside and the conventional concrete inside has been greatly improved for frost-and-crack-resistant performance of RCC gravity dam. • New technologies had deployed, including an intelligent spraying cooling system for asphalt concrete panels, an intelligent self-flow water replenishment system for reservoir, full-digital industrial TV system for the power station, and an intelligent integrated control cabinet for GIS equipment. • The project also designed a high-pressure steel bifurcation pipe that boasts an internal water pressure of 9.06 MPa and a HD value of 4140mm, and high-strength steel of 790 MPa grade. • Improved innovative technology was used to design pum turbine and generators so that they can perform efficiently under harsh freezing conditions. The motor generator's upper bracket, rotor spider and stator frame were equipped with patented oblique elements that allow thermal expansion without moving parts, resulting in a maintenance free solution. The maintenance-free oblique elements increase generator lifetime and—given their smaller foundation – decrease construction cost.
(xv)	Recommendations in Indian Context	• The Hohhot PSP plant is a good example because of its cutting-edge technology and creative design, which make it appropriate for severe freezing climates. • It takes great planning, creative design, superior management, supervision, and quality control to develop a PSP project of this magnitude (capacity 1,224MW, net head 521m) in an area where the lowest temperature can drop as low as -41,8ºC. • Similar potential PSP sites that might be available with high relative relief in Higher Himalayan valleys where harsh climatic freezing conditions prevail may be identified, planned, and developed in India

65 https://www.gevernova.com/hydropower/stories/hohhot-flexible-storage

S. No	Particulars	Description
		as a result of the successful design, construction, and operation of the Hohhot PSP project in China. • It also emphasizes the necessity of encouraging government policies and incentives to aid in the growth of PSPs. PSP development in India may be further aided by the availability of advantageous subsidies, tax breaks, low-interest investment loans, a simplified permitting process, a smooth grid connection, PSP involvement in the electricity market, etc.

5.2.3 Case Study – 3: Close-loop PSP development in Abandoned quarry/ mine

Table 5.3: Dinorwig PSP Project (1,800 MW), United Kingdom

S. No	Particulars	Description
3	Case Study	Close-loop PSP development in Abandoned quarry/ mine
(i)	Name of PSP Plant	Dinorwig
(ii)	Country	United Kingdom
(iii)	Status	Operational
(iv)	Date of Commissioning	1984
(v)	Location	It is situated in the Snowdonia National Park in Gwynedd, North Wales, in the United Kingdom, close to Dinorwig and Llanberis. It was built in the defunct slate quarry in Dinorwic. The power plant is situated deep within the mountain Elidir Fawr, inside caverns and tunnels, to protect the natural beauty of Snowdonia National Park.
(vi)	Owner	First Hydro Company (a division of Engie)
(vii)	Operated by	Central Electricity Generating Board (CEGB);
(viii)	Technical Specifications	
	Power capacity	1,800 MW (Generation) ; 2,400,000 hp (Pumping)
	Head	546.7m (Gross head)
	Turbine	Francis-type 6 units reversible pump turbines with installed capacity of each 300 MW (Generation) (400,000 hp) (Pumping)
	Generator	The power station comprises six 300 MW GEC generator/motors coupled to Francis-type reversible turbines. The generators are vertical-shaft, salient-pole, air-cooled units each having 12 electromagnetic poles weighing 10 tonnes each, producing a terminal voltage of 18 kV; synchronous speed is 500 rpm. From standstill, a single 450-tonne generator can synchronise and achieve full load in approximately 75 seconds. With all six units synchronised and spinning-in-air (water is dispelled by compressed air and the unit draws a small amount of power to spin the shaft at full speed), 0 MW to 1,800 MW load can be achieved in approximately 16 seconds (IRENA, 2020). Once running, at full flow, the station can provide power for up to 6 hours before running out of water.
	Pressure shaft Tunnel	Single concrete lined pressure shaft tunnel with a diameter of up to 10.5 m. A high-pressure manifold divides this tunnel into six concrete lined branches to serve each machine. A steel shaft lining and a reduction in the shaft diameter to that of the MIV begin shortly before reaching the underground station complex[66].

66 https://www.andritz.com/hydro-en/hydronews/hn36/dinorwig-wales

S. No	Particulars	Description
	Reservoirs	Upper Reservoir – Marchlyn Mawr reservoir is a high level lake in Snowdonia behind Elidir Fawr mountain. It is used as the high level water source for Dinorwig power station, a closed-loop pumped storage hydroelectric generating facility. Lower Reservoir: Llyn Per is a lake in Snowdonia, Wales, approximately 1.8 km long and situated close to the villages of Llanberis and Nant Peris, and the smaller twin of Llyn Padarn. The lake was formed glacially and is an example of a moraine-dammed lake. Llyn Peris is named after Saint Peris, an early Christian sai

Llyn Per lake (Lower reservoir of Dinorwig PSP) in Snowdonia, Wales, UK[67]

(ix)	**Operational Aspect**	• The facility supports the grid by providing peak load electricity. Owing to its fast response time, it also provides electricity in rapid changes in demand (IRENA, 2020), • Dinorwig is also able to provide black start services (IRENA, 2020), • The purpose of providing peak capacity, very rapid response, energy storage and frequency control. Dinorwig's very rapid response capability significantly reduced the need to hold spinning reserve on part loaded thermal plant. • Dinorwig could store cheap energy produced at night by low marginal cost plant and then generate during times of peak demand, so displacing low efficiency plant during peak demand periods. • The plant provides balancing services, including reserve and response, for the UK grid system and plays a vital role in the safeguarding of the national grid[68].
(x)	**Power evacuation**	• The power station is connected to the National Grid substation at Pentir by 400 kV cables that are buried for approximately 10 km, rather than using transmission towers or pylons to transmit the electricity across an area of outstanding natural beauty.
(xi)	**Challenges Faced**	• The power station complex consists of a series of caverns that were excavated within the slate mountain in the abandoned Dinorwic slate quarry and the main cavern is considered to be the biggest man-made cavern in Europe. These caverns house the mechanical and electrical equipment, as well as operational rooms including the control room. • The main inlet valves fulfill various important tasks in hydropower applications. From ensuring safety in powerhouses to tightly sealing waterways for maintenance on hydraulic machinery, they have to cope with a lot of conditions and need to be resilient for the intended duty at all times.

67 https://www.andritz.com/hydro-en/hydronews/hn36/dinorwig-wales
68 https://www.andritz.com/hydro-en/hydronews/hn36/dinorwig-wales

S. No	Particulars	Description
(xii)	Technological advancement	• Since the PSP plant is now 40 years old the mechanical components of this plant are approaching the end of the design life, therefore replacement or rehabilitation is mandatory. • ANDRITZ has been assigned to replace 6 Main inlet valves of all units. The installation of the first two valves in mid-2023, and the remaining fourare scheduled to be replaced by mid-2025. • The drive idea will be re-evaluated because the new MIV will have a larger and more durable main bearing. Directly mounted servomotors rather of floor-anchored ones eliminate time-consuming civil works, and double oil-controlled servomotors rather than counterweights lower overall dynamic load. In order to ensure safe operation and to take into account contemporary operating needs, the associated oil control and supply concept is specifically made to minimize the amount of oil used during movement while assuring the MIV opening time.[69].
(xiii)	Factors that contributed to the success of Dinorwig PSP Plant	• The PSP plant is successfully operating since last 40 years and it supports the grid by providing peak load electricity. Owing to its fast response time, it also provides electricity in rapid changes in demand (IRENA, 2020), • Dinorwig is also able to provide black start services, It is able to reach full load in 16 seconds (IRENA, 2020). • Dinorwig could store cheap energy produced at night by low marginal cost plant and then generate during times of peak demand, so displacing low efficiency plant during peak demand periods. • The Govt. supports PSP development through incentives, policies and programs, these include Federal Investment Tax Credit; Hydropower Production Tax Credit etc.
(xiv)	Best practices and Lessons	• The Dinorwig PSP Plant's 40 years of operation attests to its success. By supplying electricity during peak loads, it has been effectively assisting the grid. It has been supplying electricity during abrupt fluctuations in demand because of its quick reaction time. • The Plant can efficiently reach full load in 16 seconds and it is also capable to provide black start services. • Development and successful operation of large scale Dinorwic PSP plant sets a good example of proper rehabilitation of an abandoned quarry site and it demonstrates productive use of the land through proper planning and management. •
(xv)	**Recommendations in Indian Context**	• It can be found in the Snowdonia National Park in Gwynedd, North Wales, UK, close to Dinorwig and Llanberis. The former Dinorwic slate quarry served as the site for its construction. In order to protect Snowdonia National Park's natural beauty, the power plant is situated deep within caverns and tunnels inside the mountain Elidir Fawr.

69 https://www.andritz.com/hydro-en/hydronews/hn36/dinorwig-wales

S. No	Particulars	Description
		• Because there would be no excavation needed and just minimal civil building would be needed, using abandoned mine pits as PSP reservoirs could significantly save construction costs. • Studies may be takenup in India to identify potential abandoned / quarry/ mine sites that can be productively used to develop PSP. • Identifying PSP in abandoned mines may facilitate speedy development, minimize construction cost, optimum utilization of land resource, considerable reduction in land procurement process and minimizing environmental clearance process.

5.2.4 Case Study – 4: Closed- loop Conventional PSP Project using Existing Lake

Table 5.4: Ludington PSP Project (1,872 MW), USA

S. No.	Particulars	Description
4.	Case Study	Close- loop Conventional PSP Project
(i)	Name of PSP Plant	Ludington
(ii)	Country	USA
(iii)	Status	Operational
(iv)	Date of Commissioning	1973
(v)	Location	Ludington, Michigan; Coordinates: 43°53′37″N; 86°26′43″W
(vi)	Owner	Consumers Energy and DTE Energy
(vii)	Operated by	Consumers Energy
(viii)	Technical Specifications	
	Power capacity	1,872 MW
	Head	111m
	Turbine	The power plant consists of 6 reversible Francis Pump-Turbine with a capacity 312MW each and have a total output of 1,872 MW.
	Generator	455MVA each
	Penstock	Water is delivered from the upper reservoir to the turbines by six penstocks each 340 m long that taper from 8.5 to 7.3 m in diameter.
	Reservoirs	Upper Reservoir: Total capacity - 102,210,000 m3, Active capacity - 64,352,000 m^3; Surface area: 842 acres; maximum waterdepth – 34m, 4.0 km long, and 1.6 km wide which holds 27 billion US gallons (100 Gl). The 3.4 km^2 reservoir is located on the banks of Lake Michigan. The plant takes advantage of the natural steep sand dune landform of eastern Lake Michigan. Lower Reservoir: Lake Michigan; storage capacity - 4,900 km^3.; Surface ara - 58,030 km^2; Reservoir dimensions - Length – 494 km, Normal elevation - 176 m and Width – 190 km
(ix)	**Operational Aspect**	• At night, during low demand for electricity, the turbines run in reverse mode to pump water 111 m uphill from Lake Michigan (Lower Reservoir) into the upper reservoir. • During periods of peak demand water is released to generate power. • Electrical generation can begin within two minutes with peak electric output of 1,872 MW achieved in under 30 minutes. Maximum water flow is over 120,000 m^3 per minute.

S. No.	Particulars	Description
		• This process was designed to level the load of nearby nuclear power plants on the grid. • It also replaces the need to build natural gas peak power plants used only during high demand. • The plant feed electricity to six 345-kV Transmission lines[70]..

Ludington Pumped Storage Plant[71]

(x)	**Power evacuation**	Plant is connected to six 345-kV Transmission lines, all owned and maintained by METC, a subsidiary of ITC Holdings.
(xi)	**Challenges Faced**	In the foundation of upper reservoir impervious bedrock is more than 240 m deep. The upper reservoir was lined with a layer of asphalt and clay to prevent water seeping into the ground.
(xii)	Technological advancement	• Major Overhaul of pumped-storage plants pump-turbines, motor-generators, and balance of plant was undertaken by Toshiba American Energy Systems. • 1st unit returned to commercial service March 2015, 2nd unit returned to commercial service May 2016, 3rd unit received interim acceptance in June 2017, 4th unit overhaul done, 6th and final unit outage completed in 2020. • The upgradation include; Pump-turbines uprated from 312 MW to 360 MW at 320 feet of head, pump discharge increase approximately 15% at all head ranges; New motor generators with uprate from 325MVA/388 MVA (rated/overload) to 455 MVA; New thrust bearing design ; Stay vane modifications; Rotor pole refurbishment; New static excitation systems, switchgear, and isolated phase bus and Refurbishment of pony-motors[72].
(xiii)	Factors that contributed to the success of Ludington PSP Plant	• The project is efficiently operating since last over 50 years. • The PSP is efficiently balancing the grid by generating during peak load and consuming excess generation from nearby nuclear power plants in pumping during low demand. • During 2015 – 20 major E &M overhaul including; pump-turbines, motor-generators, and and other equipments was undertaken by Toshiba American Energy Systems.

70 https://web.archive.org/web/20171205093053/http://www.midwesterngovernors.org/EnergyStorage/DTEenergy.pdf
71 https://web.archive.org/web/20171205093053/http://www.midwesterngovernors.org/EnergyStorage/DTEenergy.pdf
72 https://www.toshiba.com/taes/services/hydro-turbine-generator-services/rehabilitation-technologies/ludington-pumped-storage-project :

S. No.	Particulars	Description
		• The upgradation has improved the capacity of pump turbine and generator thus, increasing the overall efficiency of the plant. • The Govt. supports PSP development through incentives, policies and programs, these include Federal Investment Tax Credit; Hydropower Production Tax Credit etc. • The market works for uniform marginal pricing.
(xiv)	Best practices and Lessons	• The Ludington PSP was developed on the bank of Lake Michigan where the Michigan Lake was used as lower reservoir for the PSP. It is aa good example which shows utilization of existing natural water body for the development of large scale (1,872 MW) PSP. • In the foundation of upper reservoir of the PSP impervious bedrock is more than 240 m. The upper reservoir was lined with a layer of asphalt and clay to prevent water seeping into the ground. The foundation treatment of the upper reservoir shows adequate measure for water tightness.
(xv)	**Recommendations in Indian Context**	• The successful execution and operation of Ludington PSP is a good example which shows adequate utilization of a natural water body for the development of PSP project. • In Indian context several such natural and manmade water bodies; lakes and reservoirs are present that can be further explored to assess the PSP potential. In India there are more than 5,200 large dam reservoirs and around 437 dam reservoirs are under construction (Kumar, 2021). • By utilizing such natural or manmade existing water bodies as reservoir/s construction cost for the development of PSP can be considerably reduced.

5.2.5 Case Study – 5: PSP Using Sea Water

Table 5.5: Okinawa PSP Project (30 MW), Japan

S. No	Particulars	Description
5.	Case Study	Using Seawater for PSP (SPSP)
(i)	Name of PSP Plant	Okinawa
(ii)	Country	Japan
(iii)	Status	Operational (1999 - July 2016)
(iv)	Date of Commissioning	1999
	De-commissioned	July 2016
(v)	Location	It is located on the northern coast of Okinawa Island, Kunigami, Okinawa, Japan (Nikolaos et al., 2023).
(vi)	Owner	Electric Power Development Company
(vii)	Operated by	Electric Power Development Company
(viii)	Technical Specifications	
	Power capacity	30 MW (Nikolaos et al., 2023). 40,000 hp
	Head	136m
	Turbine	The Francis pump turbine used in the Okinawa pumped storage hydropower project was partially made of stainless-steel resistant to seawater.
	Penstock	Fiber-reinforced plastic tubes were adopted for the penstock and the tailrace instead of steel tubes in order to avoid seawater corrosion and adhesion

S. No	Particulars	Description
		of barnacles (a marine crustacean with an external shell, which attaches itself permanently to a surface and feeds by filtering particles from the water using its modified feathery legs)
	Reservoirs	Upper Reservoir - The upper reservoir was constructed approximately 600 m away from the coastline and approximately 150 m above the sea level. It had an octagonal planar shape with a maximum width of 252m. Its maximum depth is 25 m and its effective storage capacity is 5,64,000 m^3. The entire inner surface of the reservoir was covered with an impermeable liner to prevent seawater from leaking and damaging the surrounding vegetation[73].. Lower Reservoir – Pacific Ocean
(ix)	**Operational Aspect**	The Okinawa was an experimental project operated by the Electric Power Development Company. It was the world's first pumped-storage facility to use seawater for storing energy. Its maximum output was 30 MW (Nikolaos et al., 2023). Construction of the plant started in 1987 and was completed in 1999 at a cost of ¥3.2 billion. It was dismantled in 2016.
(x)	**Power evacuation**	A 66 kV line connected the power station with the power grid of The Okinawa Electric Power Company.
(xi)	**Challenges Faced**	The major challenge in using seawater is that the metal materials can get corrosion by seawater (Hiratsuka et al., 1993). Therefore, Fiber-reinforced plastic tubes were adopted for the penstock and the tailrace instead of steel tubes in order to avoid seawater corrosion. For components such as pumpturbines a careful selection of materials is necessary. The effectiveness of additional anticorrosion countermeasures applied should be assured, not only for resistance to corrosion, but also for economy, durability and easy maintenance.
(xii)	**Technological advancement**	• The innovative concept of using seawater for pumped storage hydropower was successfully used for the first time in Okinawa PSP facility in Japan. As reported by Nikolaos et al. (2023), Okinawa PSP facility is the world's sole seawater-pumped storage hydro system. • The PSP facility using sea as lower researvoir may reduce the cost of construction by avoiding excavating and constructing a lower reservoir that otherwise is required in any close-loop conventional PSP facility. • The major challenge in using seawater is that the metal materials can get corrosion by seawater (Hiratsuka et al., 1993). Fiber-reinforced plastic tubes were adopted for the penstock and the tailrace instead of steel tubes in order to avoid seawater corrosion and adhesion of barnacles • For components such as pump-turbines a careful selection of materials was necessary. The effectiveness of additional anticorrosion countermeasure was assured. The Francis pump turbine used in the Okinawa pumped storage hydropower project was partially made of stainless steel which was resistant to seawater.
(xiii)	**Factors that contributed to the success of Okinawa PSP Plant**	• The Okinawa was an experimental project operated by the Electric Power Development Company. It was the world's first pumped-storage facility to use seawater for storing energy.

73 https://www.esru.strath.ac.uk/EandE/Web_sites/17-18/cumbrae/Seawater%20pumped%20hydro.html ; Fujihara et al., 1998

S. No	Particulars	Description
		• The power station was stopped into practical use because the demand for electric power in Okinawa had not grown as predicted, and the plant was not profitable as a business. The power plant was dismantled in July 2016. • The plant was originally built as a testing facility, and the company was able to obtain beneficial results for more than 10 years of study, before a decision to close the plant was made after considering every aspect of the operation[74].

Okinawa PSP facility that use Philippine sea water at Okinawa Island in Japan

S. No	Particulars	Description
(xiii)	**Factors that contributed to the success of Okinawa PSP Plant**	• The Okinawa was an experimental project operated by the Electric Power Development Company. It was the world's first pumped-storage facility to use seawater for storing energy. • The power station was stopped into practical use because the demand for electric power in Okinawa had not grown as predicted, and the plant was not profitable as a business. The power plant was dismantled in July 2016. • The plant was originally built as a testing facility, and the company was able to obtain beneficial results for more than 10 years of study, before a decision to close the plant was made after considering every aspect of the operation[75].
(xiv)	**Best practices and Lessons**	• The successful operation of Okinawa PSP plant for more than 10 years justify that seawater can be used for PSP purpose. However, suitable anticorrosion countermeasure for various PSP components needs to be assured. • Using sea as lower researvoir of PSP may considerably reduce the cost of construction by avoiding excavating and constructing a lower reservoir that otherwise is required in any close-loop conventional PSP facility.

74 https://www.okinawanderer.com/2016/07/experimental-power-plant-in-kunigami-dismantled/
75 https://www.okinawanderer.com/2016/07/experimental-power-plant-in-kunigami-dismantled/

S. No	Particulars	Description
		• Surplus water is always available for the smooth running of PSP Plant.The technology of using seawater is feasible, relatively economical and best suitable for coastal areas, particularly where topographical and geological conditions are favourable to construct upper reservoir and surface or underground powerhouse with desirable head.
(xv)	**Recommendations in Indian Context**	• The Okinawa PSP plant has previously demonstrated that the technique of using saltwater for PSP is feasible. • In India, this method could be used in the coastal regions of the Western Ghats that border the Arabian Sea to the west.. • Potential PSP sites around the Western Ghats, a 1,600-kilometer mountain region along the Indian peninsula's western coast, may be found with careful investigation. As a result, efforts can be made to identify locations along the shore throughout the western ghats, especially in the states of Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat, and Goa. • The Ministry of New and Renewable Energy states that the combined wind potential of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajastan, Tamil Nadu, and Telanga is 120 meters, or 676.55 GW[76]. The coastal regions of Gujarat and Maharashtra, which are located along the Western Ghats, offer a notably high potential for wind energy. In order for PSP to support intermittent generation, energy storage facilities near wind energy sources may be necessary for developing wind energy in these coastal areas.

In addition to above, Annexure 1 presents 18 additional PSP inventory that were studied in different parts of the world.

5.3 KEY LEARNINGS AND SUMMARY OF INTERNATIONAL PSP REVIEW

To understand the global status of Pumped Storage Hydropower (PSP), a comprehensive review was conducted using research articles, technical reports, and other published and unpublished web resources. The objective of this review was to identify noteworthy PSP initiatives currently underway, evaluate the performance of existing facilities, and analyze technological advancements and challenges in the development and operation of PSP. Furthermore, an effort was made to examine technical specifications, design innovations, and developments in mechanical, electrical, and civil equipment. Special focus was placed on the integration of PSP with other energy sources—particularly variable renewables like solar and wind—and its contributions to grid flexibility, among other factors. The following conclusions are drawn from a thorough analysis of global PSP development practices:

(i) With a combined capacity of more than 200 GW, PSP development is expanding quickly in a number of countries worldwide. At present, globally, about 400 PSPs are operational[77]. As per data collected from various sources, globally, about 167 PSPs are

76 https://mnre.gov.in/wind-overview/
77 https://www.hydropower.org/publications/enabling-new-pumped-storage-hydropower /

either announced or under construction, with approximately 217 GW of total installed capacity (Table 3.1 of this report). PSP is the largest renewable energy storage option. It accounts for over 90% of all long-duration energy storage worldwide, according to the International Hydropower Association (IHA). Also, PSP projects worldwide are thought to store up to 9,000 gigawatt-hours (GWh) of electricity[78].

(ii) China has the largest PSP capacity of about 53 GW (27% of total global PSP potential). With this ambitious strategy, China aims to increase PSP's installed capacity to a minimum of 62 GW by the end of 2025, 80 GW by 2027, and up to 120 GW by 2030. As of 2025, China's PSP capacity is anticipated to increase even more, with 89 GW of capacity planned or currently under construction by 2027 (IWP, 2024; https://www.hydropower.org/region-profiles/east-asia-and-pacific; USEIA, 2023).

(iii) The other countries that account for sizable PSP capacity, following China, are the United States (22 GW) and Japan (21.8 GW). The main reasons for the continued interest in PSP development in the US are its potential to supplement the US's growing renewable energy supply and to offer crucial capacity, flexibility, energy balancing, grid stability, and long-duration (8–12 hours) energy storage [79]. Additionally, the US has set goals to have a 100% clean energy economy by 2050 and a PSP capacity of 30 GW by 2030.

Further, in Japan, with facilities like the Okinawa Yanbaru Seawater Pumped Storage Power Station—a unique facility that has employed seawater for energy storage—the nation is a global leader in PSP technology. Regarding new projects and construction: in order to improve its energy infrastructure even more, Japan continues to fund the creation of new PSP projects. The Kannagawa Hydropower Plant is one such undertaking. The Kannagawa Hydropower Plant (KHP) in Nagano, Japan, is operating partially as of February 2024. With a 2.6 GW capacity, this project will rank among the biggest PSP plants globally. The Japanese government is also actively looking for collaborations and funding to identify additional potential PSP locations across the nation.

(iv) Europe has notable PSP capacity in countries like Germany (9.3 GW), Italy (7 GW), France (5.8 GW), and Spain (5.6 GW). In Germany, the Gaildorf Project—a hybrid wind and PSP project in Baden-Württemberg—is being developed by Max Bögl Wind AG and is anticipated to be put into service in 2025. Additionally, EnBW started building a new PSP station at Forbach, in the southern state of Baden-Württemberg, in January. In order to transform the 71 MW Rudolf-Fettweis-Werk (RFW) conventional hydropower complex into a pumped-storage facility, EnBW plans to invest roughly €280 million (Hydropower & Dams, 2024). By 2030, the German energy system's capacity of pumped storage hydro power plants is anticipated to increase by roughly 1.4 GW. Similarly, in Spain, as of 2024, six PSP projects with a total installed capacity of 2.5 GW and over 740 GWh of energy storage are in the permitting stage or under construction[80]. In accordance with the previous PPE's goal of adding 1 to 2 GW of pumped storage

[78] https://www.hydropower.org/factsheets/pumped-storage
[79] https://www.nrel.gov/news/press/2023/news-release-nrel-analysis-reveals-benefits-of-hydropower-for-grid-scale-energy-storage.html
[80] https://www.hydropower.org/region-profiles/europe

between 2025 and 2030, EDF in France announced in 2018 a new storage plan of more than 10 GW of new storage by 2035, which includes provisions for up to 2 GW of new pumped storage and 1 GW of conventional storage (Hydropower and Dams, World Atlas, 2022).

(v) A number of other countries, including India, Portugal, Australia, and many more, are currently exhibiting faster growth, and PSP is in different stages of development. Currently, in India, 57 projects that are presently going through different stages of planning, development, and building would put India among the top countries in terms of PSP status in the near future, according to the country's PSP status as of February 2025. An extra 74.58 GW of installed capacity will result from these projects (CEA, 2025d). Similarly, Australia is promoting the potential of wind and solar photovoltaics; at a growth rate of about 1 to 2 GW annually, it is anticipated that by 2030, 50% of Australia's electricity will come from renewable sources. Energy storage will therefore be necessary for grid balancing due to the rapid expansion of wind and solar PV power. According to the Australian Renewable Energy Agency (ARENA), this is the main factor driving PSP expansion in Australia, coupled with supportive policies

(vi) Technological progress in PSP is being made to enhance;

- Equipment efficiency - Variable Speed, Ternary and Quaternary technology
- Innovative PSP technology is being developed - to incorporate cost-effective design, changeable renewable energy, seawater, existing reservoirs, abandoned mines, etc.

(vii) Many prominent countries have developed legislative frameworks and supportive policies to encourage PSP establishment and operation. The development of PSP is currently expanding more quickly. Among many countries, China has established encouraging PSP support through a number of policies that are beneficial to the PSP market, including: financial incentives; tax breaks; allowing PSP plants to generate revenue by providing grid stability services through participation in ancillary service markets; streamlined permitting processes and clear guidelines for PSP development; seamless connection to the grid and participation in electricity markets; balancing PSP development with environmental considerations, such as water resource management and ecological impact; and promoting a competitive PSP market by encouraging diverse ownership and participation (China Energy Portal, 2021; Papadakis et al., 2023).

(viii) A number of case studies from China, the United States, Japan, and Australia offer practical PSP technology based on experience that can be used to create new PSP initiatives. Some of such case studies are summarized below;

Changlongshan PSP in China (2.1 GW)

- Highest-rated head (710m)
- 6 x350 MW Francis pump turbine
- 2 different rated speed of 500 and 600 rpm/min with a capacity of 350 MW each.
- It is adding an average of 2.435 billion kWh of electricity to the grid each year during peak hours.
- The success of PSP highlights the need for adopting advanced technology and following high-quality management for the development of new PSP projects.

Upper Reservoir of Changlongshan PSP

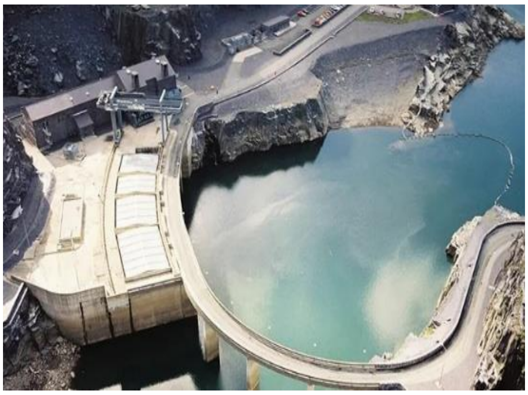
Hohhot PSP in China (1.2 GW)

- Innovative design for harsh conditions (-41.8 °C)
- The PSP plant is complementing wind farm production
- Meeting the needs of new energy. approx. 2.007 billion kWh annually.
- This project indicates possibilities to identify and develop potential sites in higher Himalaya, particularly in the states of J &k, Himachal, Uttrakhand and North eastern states.

Upper Reservoir of Hohhot PSP

Dinorwig Close-loop PSP development in Abandoned quarry/ mine in UK (1.8 GW)

- PSP operating since last 40 years.
- Good example of proper rehabilitation of an abandoned quarry site.
- Similar abandoned mines can be identified and studied to explore for the possibilities to develop PSP in India.
- May considerably reduce the construction cost as no excavation would be required and minimum civil construction would be required.



Dinorwig PSP in Abandoned mine. UK

Ludington Close- loop Conventional PSP Project (1.87 GW) in USA

- Efficient operating since last over 50 years
- Efficiently balancing the grid.
- By utilizing existing water bodies.
- In Indian context several such natural and manmade water bodies; lakes and reservoirs are present that can be further explored to asses the PSP potential.

Ludington PSP Project, USA

Okinawa PSP Project (30 MW), Japan

- This plant has established the feasibility of using seawater for PSP development.
- This technology may be adopted in the Western Ghats coastal areas.
- Efforts can be made to locate sites all along the western ghats that is close to the coastal area particularly in the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala, and Tamil Nadu.

Okinawa PSP Project, Japan

5.4 LEARNING FOR INDIA

Based on the international review of PSP development regarding technical details, design advancements, integration with other energy sources (especially variable renewables like solar and wind), contributions to grid flexibility, and supportive government policies, the following learnings are drawn to support PSP development in India:

(i) Implementation of supportive positive Government policies that are beneficial for the PSP development.

(ii) Provision of financial incentives, including subsidies, tax breaks, and low-interest investment loans to promote PSP growth.

(iii) Establishment of streamlined permitting processes and clear guidelines for PSP development. In this regard, the Ministry of Power, Government of India, released the "Guidelines to Promote the Development of Pumped Storage Projects" on April 10, 2023[81], in recognition of the necessity for the rapid and economical development of PSPs.

(iv) Facilitating seamless connection of PSP projects to the grid and establishing clear regulations for their technical integration

81 https://powermin.gov.in/sites/default/files/webform/notices/Guidelines_to_Promote_Development_of_Pump_Storage_Projects.pdf

(v) Market Participation: Allowing PSPs to participate in the electricity market to generate revenue by providing grid stability services through participation in ancillary service markets.

(vi) Asset Recognition: Promoting and recognizing PSP as a grid asset so that its role is well-defined as a provider of flexibility and stability, rather than being considered a simple generating unit.

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CHAPTER 6: APPRAISAL OF PSP POTENTIAL IN INDIA

6.1 OVERVIEW

India revealed its five-point climate action plan, known as **Panchamrit**, at the United Nations Climate Change Conference in Glasgow (COP26). These goals include:

(i) achieving 500 GW of non-fossil fuel energy capacity by 2030;
(ii) meeting 50% of energy requirements from renewable energy by 2030
(iii) reducing total projected carbon emissions by one billion tonnes between now and 2030;
(iv) reducing the carbon intensity of the economy by 45% by 2030 from 2005 levels; and
(v) reaching the goal of net-zero emissions by 2070[82].

India intends to utilize wind and solar energy as its primary renewable sources to meet these objectives. However, due to the inherent intermittency and fluctuation of these sources, it is challenging to maintain grid balance and ensure that consumers receive high-quality power—a critical indicator of a country's development.

To integrate large capacities of renewable energy into India's grid while maintaining stability and power quality, energy storage solutions will become increasingly crucial. Among all grid-scale energy storage technologies currently available on the market, **Pumped Storage Projects (PSPs)** are the most established and have the longest operational history, both in India and globally[83].

6.2 PSP AS A TOOL FOR GRID MANAGEMENT

PSPs offer a number of advantages for grid management when renewable energy levels are high, such as:

(i) **Primary Support to the Power System:** To maintain grid balance during off-peak hours, a PSP primarily serves as a demand source, using excess grid electricity to pump and store water in the upper reservoir. The PSP later serves as a supply source during periods of high demand by supplying the grid with electricity generated from the stored water.

(ii) **Ancillary Services:** Apart from load balancing, PSP offers auxiliary services as well. These are essential for the power system to ensure dependability and prevent grid operation disruptions (Pérez-Díaz JI et al., 2014).

(iii) **Voltage Support and Reactive Power:** PSP technology offers voltage support to keep voltage levels nearly constant under a variety of load conditions. By offering reactive power balancing services, the PSP can provide voltage regulation. Reactive control is a crucial instrument for controlling voltage and maximizing the use of available power. PSP has the ability to operate in synchronous condenser mode to increase the system power factor.

82 https://pib.gov.in/PressReleasePage.aspx?PRID=1795071
83 https://iitr.ac.in/Departments/Hydro%20and%20Renewable%20Energy%20Department/static/special_publ/Advanced_grid-scale_energy_storage_technologies_Nov_2023_HRED_IIT_Roorkee.pdf

(iv) **Frequency Control:** Nominal grid frequency must be maintained through frequency regulation. Frequency fluctuation results from a mismatch between the demand curve and electricity generation. PSP can keep the power system free from fluctuations and maintain a constant frequency within the desired range (typically 50 Hz). To maintain a steady frequency, electricity can be drawn from the grid for pumping mode operation when the frequency is above 50 Hz, and the PSP can operate in generating mode when the frequency falls below 50 Hz.

(v) **Black Start or System Restart:** PSP can offer crucial assistance in restoring the system during a complete or partial blackout. In the event of a total outage, PSP can quickly supply the electrical system with an immediate power source.

(vi) **Spinning Reserve:** The amount of stored capacity in a PSP asset that may be used to compensate for frequency decreases or power outages within a specific timeframe is known as the spinning reserve. As a result, PSP helps the grid remain stable during demand fluctuations, unexpected outages, or load failures.

(vii) **Ramping Capability:** A PSP plant can ramp up from idle to full production capacity in less than two minutes and from 50% to full capacity in roughly 15 seconds. Similarly, depending on the plant configuration, it can go from a standstill to full pumping capacity in less than five minutes. With a ramping capability of approximately 200 MW/min, PSPs are more effective and comparatively more cost-saving in start-up and shutdown operations than other sources, such as thermal plants.

(viii) **Peak Shaving:** A PSP's strong ramping capabilities allow it to quickly fulfill peak demand without requiring a minimum load to function. As a result, PSP offers a unique capacity to restore the power system steadily.

Furthermore, the need for large-capacity, long-duration energy storage will grow as a result of climate change and rising levels of renewable energy; PSP remains the best choice for this application[84]. For instance, the Bath County PSP plant in the USA, with a rated power output of approximately 3 GW and an energy capacity of 24 GWh, has been in operation for more than 30 years and can generate 3 GW of power for eight hours[85]. These factors have led to a surge in interest in PSP development in India in recent years, particularly following the Indian Government's pledge to increase non-fossil fuel electricity generation.

6.3 LONG-TERM STRATEGY FOR THE DEVELOPMENT OF PUMPED STORAGE HYDRO

Longer periods of low Variable Renewable Energy (VRE) generation will have a greater impact as a higher proportion of total energy generation is composed of VRE resources. Consequently, long-term energy storage will be increasingly required to bridge these gaps. For decades, hydrological droughts have affected hydropower production on a seasonal, yearly, or even multi-year basis. Historically, these gaps have been partially filled by other adaptable resources; dispatchable thermal generating facilities, in particular, have addressed these deficiencies by providing the system with the necessary power and energy capacity flexibility. However, as the current fleet of thermal generators must eventually be mostly or completely retired to support decarbonization, alternative resources will be needed to provide this

84 https://ldescouncil.com/
85 https://www.dominionenergy.com/projects-and-facilities/hydroelectric-power-facilities-and-projects/bath-county-pumped-storage-station

flexibility. Long-Duration Energy Storage (LDES) technologies[86] will be crucial in bridging the gap between growing electricity demand and an increasingly erratic supply.

Extended periods of low solar and wind output can be characterized as "resource droughts." The frequency and duration of these droughts are significant indicators of the potential need for LDES, as they demonstrate a mismatch between VRE generation and demand that would be prohibitively expensive to mitigate through the over-building of VRE generation alone. Short-duration energy storage will not suffice to fill these gaps in regions where VRE resource droughts last for days or weeks. Furthermore, no amount of additional wind or solar capacity can meet system demand if availability remains extremely low throughout the power system area. These protracted drought occurrences are likely to occur more frequently due to the impacts of climate change.

Figures 6.1 and 6.2 illustrate the disparity in the adoption of renewable energy between European nations, based on data from 2015 to 2020 [87].

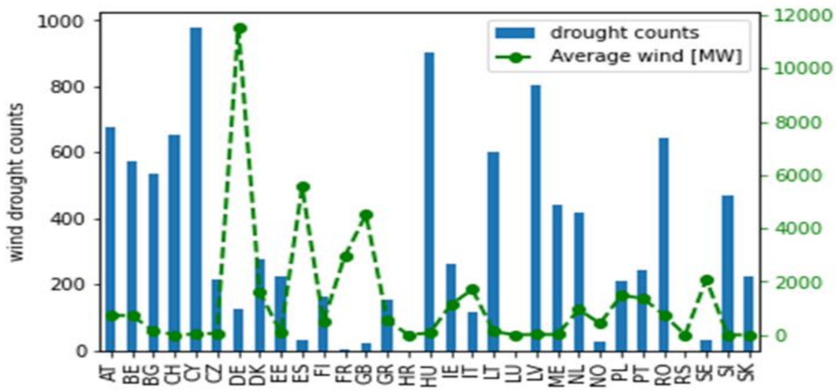

Figure 6.1: Wind Drought Counts by European Countries

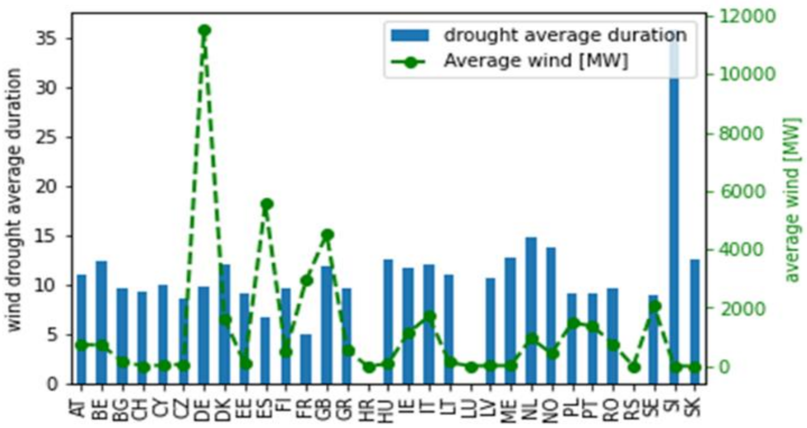

Figure 6.2: Wind Drought Duration (Hour by European Countries

86 LDES is energy storage assets with a duration longer than 8 hours. https://www.ldescouncil.com, https://www.energy.gov/eere/long-duration-storage-shot

87 Open Power System Data. 2020. Data Package Time series. Version 2020-10-06. https://doi.org/10.25832/time_series/2020-10-06. (Primary data from various sources, for a complete list see URL).

6.4 PUMPED STORAGE HYDROPOWER POTENTIAL IN INDIA[88]

According to the Central Electricity Authority (CEA), as of October 2025, the total PSP potential in India is estimated at 224 GW. This includes approximately 59 GW of on-river PSP potential and 165 GW of off-river PSP potential. Out of the 197 identified PSP locations, 65 are situated on rivers and 132 are off-river sites.

For the purpose of assessing PSP potential, the nation is divided into five regions: the Northern, Western, Southern, Eastern, and North-Eastern Regions (Figures 6.3 and 6.4). The Western Region possesses the highest potential, with approximately 89.69 GW across 78 possible PSP sites. This is followed by the Southern Region, which has 64 potential locations and a capacity of roughly 69.8 GW. According to Table 6.1, the potential of the Northern, Eastern, and North-Eastern Regions is approximately 39 GW, 16.39 GW, and 8.23 GW, respectively. Among all states, Maharashtra and Andhra Pradesh hold the highest potential at roughly 55.85 GW and 32.75 GW, respectively. The region-wise breakdown of total PSP potential in India is presented in Table 6.1.

Table 6.1: Region wise total PSP Potential in India [89]

Region	State	PSP On-River		PSP Off-River		Total	
		No of projects	Installed capacity (MW)	No of projects	Installed capacity (MW)	No of projects	Installed capacity (MW)
Northern	Himachal Pradesh	2	2,330	4	4,930	6	7,260
	Rajasthan	0	0	9	12,560	9	12,560
	Uttarakhand	2	1,600	1	400	3	2,000
	Uttar Pradesh	0	0	11	17,620	11	17,620
	Sub Total (NR)	**4**	**3,930**	**25**	**35,510**	**29**	**39,440**
Western	Madhya Pradesh	1	640	8	9,420	9	10,060
	Chhattisgarh	2	825	10	11,775	12	12,600
	Gujarat	2	1,440	12	9,740	14	11,180
	Maharashtra	17	14,305	26	41,550	43	55,855
	Sub Total (WR)	**22**	**17,210**	**56**	**72,485**	**78**	**89,695**
Southern	Andhra Pradesh	4	4,750	22	28,000	26	32,750
	Telangana	2	1,605.60	5	7,150	7	8,755.6
	Karnataka	2	3,500	6	4,100	8	7,600
	Kerala	2	1,200	0	0	2	1,200
	Tamil Nadu	15	12,300	6	7,200	21	19,500
	Sub Total (SR)	**25**	**23,355.60**	**39**	**46,450**	**64**	**69,805.60**
Eastern	Jharkhand	1	1,500	0	0	1	1,500
	Odisha	1	500	7	6,415	8	6,915
	West Bengal	6	5,500	0	0	6	5,500
	Bihar	0	0	3	2,480	3	2,480
	Sub Total (ER)	**8**	**7,500.00**	**10**	**8,895**	**18**	**16,395**
	Assam	1	320	1	900	2	1,220

[88] Potential estimation of PSP is under going dynamically in the country as several new sites are being identified by different stakeholdes. Data presented here are based on 20.08.2025 available from CEA (https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/08/PSP_Potential.pdf) and MOEFCC–EC sites.

[89] PSP Potential in the country is under going dynamically as several new sites are being identified by different stakeholdes. Data presented here is based on status report of Oct.2025, available from CEA (https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf)
and MOEFCC–EC sites.

Region	State	PSP On-River		PSP Off-River		Total	
		No of projects	Installed capacity (MW)	No of projects	Installed capacity (MW)	No of projects	Installed capacity (MW)
North Eastern	Arunachal Pradesh	1	660	0	0	1	660
	Mizoram	4	5,550	0	0	4	5,550
	Tripura	0	0	1	800	1	800
	Sub Total (NE)	**6**	**6,530.00**	**2**	1,700	8	**8,230**
	Grand Total	**65**	**58,525.6**	**132**	**165,040**	**197**	**2,23,565.6**

Source: CEA (2025), (Status as on Oct.2025) https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf

Additionally, PSPs can be developed in abandoned mines. In India, seawater PSPs can also be developed, especially in the Western Ghats highlands along the Arabian Sea coast. Further, the Coal Ministry has identified roughly 20 abandoned mines that may be used to assess whether setting up PSPs is feasible or not (MoP, 2024a; Ministry of Coal, 2023).

6.5 EXISTING PSP PLANTS IN INDIA

Even though PSPs were first utilized in India in the late 1970s, when the Nagarjuna Sagar PSP plant in Telangana was put into service, an additional nine PSP plants have subsequently been added to the Indian electricity grid (Table 6.2). Initially, the PSP received attention for grid support and balance in connection with nuclear facilities. However, in recent years, to integrate large amounts of renewable energy into India's system while maintaining grid stability and power quality, PSP is now being promoted at an accelerated rate.

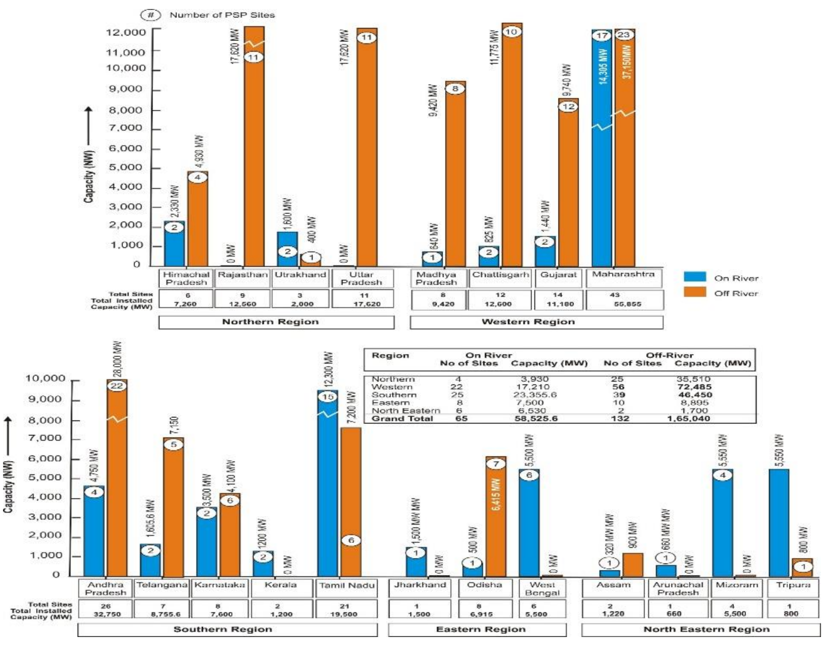

Figure 6.3: State Wise PSP Potential in India[90]

Source: CEA (2025), (Status as on Oct.2025)

[90] PSP Potential in the country is under going dynamically as several new sites are being identified by different stakeholdes. Data presented here is based on status report of Oct.2025, available from CEA (https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf) and MOEFCC–EC sites.

At present, eight PSPs (80%) currently operate in both generating and pumping modes, while the remaining stations are only operating in the generating mode due to operational and development concerns. A total of 10 projects with a total capacity of 6,685.6 MW were commissioned as PSPs. Out of these, eight PSP plants are operating in both pumping and generation modes and have a total installed capacity of 5,245.6 MW. Presently, Sardar Sarovar PSP (1,200 MW) and Kadana PSP (240 MW) are not operational in pumping mode [91]. However, efforts are being made to make these two PSPs fully functional so that they can also be operated in pumping mode. Table 6.2 displays the evolution of the main PSP projects in chronological order. Information about these plants can be found in Annexure-2.

Figure 6.4: Region Wise PSP Potential in India

Source: CEA (2025), (Status as on Oct.2025)

*(*https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf*)*

6.6 PSP PROJECTS CURRENTLY NOT OPERATING IN PUMPING MODE

The Kadana PSP project (240 MW) in Gujarat and Sardar Sarovar (1,200 MW) in Gujarat are PSP schemes that are not running in pumping mode for a variety of reasons (Table 6.3) (CEA, 2025; status Oct. 2025[92]).

[91] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_In_Operation.pdf

[92] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_In_Operation.pdf

Table 6.2: Historic development of PSP Projects in India (Status Oct. 2025)[93]

S No	Name of PSP	State	No of units x Unit size (MW)	Installed capacity (MW)	Commissioning Year	Project Operated by	Status
1	Nagarjuna Sagar	Telangana	7x100.60	705.6	1980 (100.8 MW) 1981 (100.8 MW) 1982 (100.8 MW) 1983 (100.8 MW) 1984 (100.8 MW) 1985 (202 MW)	TSGENCO	Operational
2	Kadamparai	Tamil Nadu	4x100	400	1987 (100 MW) 1988 (200 MW) 1989 (100 MW)	TANGEDCO	Operational
3	Bhira	Maharashtra	1 x 150	150	1927 (125 MW) 1949 (25 MW)	TPCL	Operational
4	Kadana	Gujarat	4 x 60	240	1990 (120 MW) 1998 (120 MW)	GSECL	Not Operating in Pumping
5	Srisailam LBPH	Telangana	6x150	900	2001 (300 MW) 2002 (450 MW) 2003 (150 MW)	TSGENCO	Operational
6	Sardar Sarovar	Gujarat	6x200	1,200	2005 (800 MW) 2006 (400 MW)	SSNNL	Not Operating in Pumping
7	Ghatghar	Maharashtra	2x125	250	2008 (250 MW)	MAHAGENCO	Operational
8	Purulia	West Bengal	4x225	900	2007	WBSEDCL	Operational
9	Tehri	Uttrakhand		500	2025 (500 MW)	THDC	Operational
10	Pinnapuram	Andra Pradesh		1,440	2025 (1,440 MW)	Greenko AP01 IREP Private Limited	Operational
			Total	**6,685.6**			

Source: CEA (2025)(https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_In_Operation.pdf)

Table 6.3: PSP projects presently not operating in Pumping Mode

SP Name	Installed capacity (MW)	About Project	COD	Reason – Not operational
Sardar Sarovar	**1,200 (6 x 200 MW) (**Francis vertical Reversible turbine) + 250 (5 x 50 MW) (Kaplan turbine-generators)	The project is situated in Gujarat state's Nandod district, close to Navagam town. The project is executed by Sardar Sarovar Narmada Nigam Limited (CEA, 2023a).	2004 - 2006	The project is working in generation. To run the project in pumping mode efforts are under Process (CEA, 2025; status as on Oct. 2025) https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_In_Operation.pdf
Kadana	240 (4 x 60 MW) (Francis turbine/ Pump)	The project is situated in Gujarat State's Mahisagar District Panchmahals on the banks of the Mahi River. The project is executed by Gujarat State Electricity Corporation Ltd (GSECL). (CEA, 2023a)	1990	The project is working in generation. To run the project in pumping mode efforts are under Process (CEA, 2025; status as on Oct. 2025) https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_In_Operation.pdf

Source: CEA (2025) https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_In_Operation.pdf

[93] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_In_Operation.pdf

6.7 MANAGING PSP PLANT OPERATIONS IN INDIA – CURRENT PRACTICE

In India, the state distribution utilities or producing utilities own and operate the majority of PSP plants that are currently in pumping mode. In Maharashtra, Tata Power owns and operates the Bhira PSP (150 MW) project, while Mahagenco[94] owns the Ghatghar PSP (250 MW) project. These plants are operated by the State Load Dispatch Centers (SLDCs) in accordance with the station's surplus stored energy and peaking requirements. Furthermore, state distribution companies (Discoms) are responsible for running PSP plants according to the directives they receive from the relevant SLDCs regarding generation needs during peak loads.

The PSP plants function as a demand source for basic grid balancing support during off-peak hours, using surplus grid electricity to pump and store water in the upper reservoir. The PSP later serves as a supply source during periods of high demand by providing the grid with electricity generated from the stored water. Current PSP plants can be transitioned into pumping mode within five minutes of a command and into generating mode to meet their maximum load.

For instance, the Ghatghar PSP has two 125 MW units that together produce 250 MW of power while requiring 150 MW for pumping. According to SLDC directives, both units operate for seven hours during off-peak pumping and six hours for peak-load generation from Monday through Saturday. On Sundays, both units are operated in pumping mode in accordance with SLDC directives. It takes three minutes for both units to achieve their full load (125 MW each) in generation mode, whereas it can take up to five minutes for both units to begin pumping. Maharashtra State Electricity Distribution Company Ltd. (MSEDCL) and Maharashtra State Power Generation Co. Ltd. (MSPGCL) have a barter system in place for energy accounting. Under this arrangement, MSEDCL does not bill the PSP for energy used during pumping, and MSPGCL does not bill MSEDCL for the energy supplied by the Ghatghar PSP.

Only MSPGCL is responsible for the O&M (Operation and Maintenance) and lease rent fees. Similarly, the West Bengal Electricity Regulatory Commission (WBSERC), the state regulator, sets the pricing for the Purulia PSP (4 x 225 MW). WBSEDCL recovers the plant's total capital and operating costs through the distribution tariff. In accordance with SLDC instructions and the WBSEDCL demand pattern, the utility generates energy during peak hours and provides pumping energy during off-peak hours. Each 225 MW unit absorbs 250 MW of power during pumping, while each unit generates 225 MW during generation. Each unit reaches full load during both pumping and generation within five minutes. The daily schedule typically calls for six hours of generation during peak-load periods and six to seven hours of pumping during off-peak periods[95].

Although PSPs can offer a variety of ancillary services to the grid, they are not fully utilized for this purpose because the majority of states lack comprehensive primary, secondary, and tertiary ancillary service regulations. Resources like PSP are permitted to offer secondary and tertiary ancillary services under the recently authorized Ancillary Service Regulations of 2022.

94 https://www.mahagenco.in/about-us
95 https://posoco.in/en/download/fold-posoco-report-on-operational-analysis-for-optimization-of-hydro-resources/?wpdmdl=14168

As discussed later in this report, these regulations include critical definitions of ancillary services.

The Primary Reserve Ancillary Service (PRAS) aids in clearing transmission network congestion and restoring the frequency to the intended level. It has a 5- to 10-second response time to a frequency signal and a 5-minute endurance period. Similarly, the Secondary Reserve Ancillary Service (SRAS) is an ancillary service that may be activated and deployed via a secondary control signal. It consists of SRAS-Up and SRAS-Down. When SRAS-Up receives a signal from the Nodal Agency, it either increases the injection of active power or decreases drawal/consumption, as required. Conversely, in response to a signal, SRAS-Down either increases drawal/consumption or decreases the injection of active power.

Additionally, the Tertiary Reserve Ancillary Service (TRAS) includes TRAS-Up and TRAS-Down, encompassing both spinning and non-spinning reserves that react to the Nodal Agency's dispatch instructions. In response to these instructions, TRAS-Up increases active power injection or decreases drawal, while TRAS-Down decreases active power injection or increases drawal (CERC, 2022). Table 6.4 provides the key requirements for PRAS, SRAS, and TRAS.

Between October 28 and November 24, twelve Automatic Generation Control (AGC) hydroelectric units provided SRAS services. These units accounted for 3,265 MWh of total up-regulation and 3,852 MWh of total down-regulation, resulting in a total net energy of -586 MWh. According to the CERC judgment, the markup costs were Rs. 29,83,360, while the variable charges amounted to Rs. 11,00,474. From October 28, 2024, to November 24, 2024, SRAS providers received a total of Rs. 18,82,886 in charges from the Deviation Settlement Mechanism (DSM) Pool (NLDC, 2024). Hydropower plants also offer primary frequency response, load-following ancillary services, and inertia support.

Table 6.4: Reserves and their Activation

Reserve	**Start of activation**	**Full Availability/ deployment**	**Ability to sustain the full deployment**
Primary Response	Immediately as soon as frequency crosses the dead band	Within 45 seconds	Upto 5 min
Secondary control Reserve	Within 30 seconds after the receipt of Automatic Generation Control (AGC) signal	within 15 Minutes	Up to 30 min or till replaced by Tertiary Reserves
Tertiary control Reserve	Within 15 minutes of dispatch instruction from NLDC/RLDC		Upto 60 minutes

Source; CERC (2023)

6.8 MAJOR CHALLENGES FACED IN RECENT PSP CONSTRUCTION IN INDIA

PSP initiatives are still in their infancy stage in India, and there is a dearth of knowledge regarding the challenges that arise during implementation. However, some of the difficulties for the following PSP projects, which are nearing the end of construction, are addressed as follows:

6.8.1 Tehri – II PSP Project

The Tehri St-II PSP is now producing 500 MW of peak output. The Tehri Hydro Development Corporation (THDC) is operating the project. The following are the primary challenges that were faced during the construction of Tehri-II PSP:

(i) Complex Geological Setup: One of the biggest challenges was in excavating enormous caverns under unstable geological circumstances. To provide safe excavation conditions, oversized surge shaft chambers had to be remodeled and widened from 25 to 15 meters. Additionally, the large cavern excavations had to be managed under unstable geological conditions. As a result, the timeline has been delayed and the cost has increased.
(ii) Design and drawings: The completion of the design and drawings was delayed due to changed geological conditions and other complexities.
(iii) Budgetary restrictions: The project encountered budgetary difficulties, such as delays and cost overruns [96].
(iv) Social and environmental effects: The project caused ecological imbalance and human dislocation, among other social and environmental effects.
(v) Sediment issues: It was challenging to determine the sedimentation rate precisely due to lack of adequate sediment data.
(vi) Pandemic: The civil contractor had financial difficulties as a result of COVID-19 epidemic.
(vii) Additional difficulties Devastation from earthquakes, decreased river flow, and political instability[97].

6.8.2 Pinnapuram integrated renewable energy project (IREP)

In Andhra Pradesh's Kurnool District, the IREP is intended to be one of the first and biggest integrated projects in history. A 1,440 MW pumped storage hydropower facility, a 550 MW wind farm, and a 1,000 MW solar farm make up the 2.9 GW hybrid renewable energy project. During its development, the IREP encountered a number of difficulties. An upper and lower reservoir, each with a storage capacity of 1.2 thousand million cubic feet (TMC), are part of the standalone pumped hydroelectric power component. They are surrounded by rockfill dams that are 40 meters high and 9.6 kilometers long, with average embankment heights of 18 to 20 meters. This adds to the project's technical complexity and necessitates costly engineering solutions. With five or six distinct types of rock and soil present, the project site exhibits a variety of geological characteristics. When building the open deep-cut tunnel slopes, the main problem was forecasting how weak soil sections would behave when they disintegrated between the reservoir bodies. The substantial demand for financing is also explained by the fact that the two reservoirs are off-stream closed loops that are situated at a distance from the main water supply[98].

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[96] https://merc.gov.in/wp-content/uploads/2024/09/Order-in-Case-No.156-of-2024.pdf

[97] https://www.smec.com/project/tehri-pumped-storage-project/#:~:text=One%20of%20the%20main%20challenges,carried%20out%20accurately%20and%20safely.

[98] https://renewablewatch.in/2024/09/25/india-designs-worlds-first-and-largest-integrated-renewable-energy-project/

CHAPTER 7: RECENT TRENDS IN PSP DEVELOPMENT IN INDIA

7.1 OVERVIEW

An effort was made to gather all possible PSP data from various sources for the current study. These consist of published reports, minutes from different EAC MoEF&CC approval sessions for PSP projects, CEA's PSP status reports, and other online resources. PSP development status reports issued by the CEA in February, June, and September 2024, as well as in February, August, and October of the current year (2025)—with the most recent being in October 2025 (CEA, 2025[99])—and a report on the Reassessment of the Hydroelectric PSP Potential of India by the CEA (CEA, 2023a) provided a thorough compilation of PSPs in India. Additionally, personal visits and consultations with relevant government officials, agencies, and other PSP development stakeholders were conducted to collect firsthand experiences regarding PSP development across various states in India.

7.2 PSP POTENTIAL IN INDIA – A REASSESSMENT BY CEA (CEA, 2023A) [100]

In order to determine India's PSP potential, the CEA performed a survey between 1978 and 1987, where 96.5 GW potential of 63 sites were identified. The highest potential identified was in the Western Zone with 39.6 GW (29 sites), followed by the Southern Zone with 17.7 GW (10 sites). These sites and others were re-evaluated by the CEA in June 2023 and found 61 sites having potential of 59 GW suitable for development, whereas 34 sites having potential of 46 GW were found non-exploitable for a variety of reasons (CEA, 2023a).

In addition, off-stream PSP sites are being self-identified by developers and, as of October 2025, there are a total of 197 PSP sites that can be exploited/exploitable, having a total potential equal to 223 GW[101]. Out of this, 65 on-stream PSP sites with a total of 58 GW of exploited/exploitable PSP potential (above 25 MW) and 132 off-stream PSP sites with a combined capacity of 165 GW are available.

7.3 A COMPILATION OF PSP POTENTIAL ASSESSMENTS FROM VARIOUS SOURCES

For the first step, various government and private power companies perform their own PSP potential assessments and send their pre-feasibility reports to the Ministry of Environment, Forest and Climate Change (MoEFCC) for the approval of the Terms of Reference (ToR) for carrying out an Environmental Impact Assessment (EIA) study. For the MoEFCC to consider granting authorization for the ToR, the state government's consent to conduct the EIA study is a necessary document. Following receipt of the ToR from the MoEFCC expert committee, these are examined further for the purpose of conducting an EIA and conducting in-depth research in order to prepare the Comprehensive Project Report (DPR). Although it is merely a submission for information, some developers additionally ask the Central Electricity Authority (CEA) to obtain the first-stage clearance for their PSP. The Central Water Commission (CWC),

[99] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf

[100] https://cea.nic.in/wp-content/uploads/hp___i/2023/08/Pumped_Storage_On_River_Final_compressed.pdf

[101] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf

the Geological Survey of India (GSI), and the Central Soil and Materials Research Station (CSMRS) are sibling organizations of the CEA.

After analyzing data gathered from many sources for this study, about 232 PSP sites were found, spread over 21 states in the country (Table 7.1). These sites have a combined capacity of roughly 270 GW. Of the 232 PSP sites, 100 were found to be on-river, with a combined potential of roughly 105 GW, and 132 were found to be off-river, with a combined potential of roughly 165 GW. However, 35 of the 232 PSP sites that were identified had a capacity of roughly 46 GW and were determined to be unexploitable for a variety of reasons, including being in a restricted area or not being feasible for a number of reasons (Table 7.1). As a result, there are 197 feasible PSP sites with a combined potential of roughly 223 GW (status as of October 2025, CEA, 2025) [102]. Annexures 3 and 4 (b) contain a table with information about various PSP sites that were found from various sources.

Table 7.1: Summary of Identified PSP sites in various states – developed, Under various stages of development or dropped due to various reasons

S. No.	Particulars	PSP	
		Number	Capacity (GW)
1.	Total PSP sites in various states identified, developed, under various stages of development or dropped due to various reasons (Based on Review conducted during present study)	**232**	**269.89**
2.	Total On-stream PSP sites (Status as on Oct' 2025 CEA, 2025)	65	58.52
3.	Total Off-stream PSP sites (Status as on August' 2025 CEA, 2025)	132	165.04
4.	Total PSP sites Operating[103].	10	7.42
5.	DPR concurred	5	6.58
6.	Under construction (Status October' 2025 CEA, 2025)	11	12.11
7.	Sites Under survey and investigation (Status October' 2025 CEA, 2025)	52	73.09
8.	Yet to be allotted by the state for development	31	34.58
9.	Sites in other stages of development; PFR, Preliminary studies, TOR Granted etc	89	89.78
10.	Total number of PSP sites in operation or under different stages of development	197	223.56
11.	Sites un-exploitable (Not feasible / fall in restrictrd area)	35	46.33

(Source: Annexures 3 and 4 (b) contain a table with information about various PSP sites and the data source used)

With 43 PSP sites and a combined capacity of roughly 55 GW, Maharashtra had the most PSP sites. Andhra Pradesh came next, where 26 sites with a combined potential of roughly 26 GW were found. A total of 21 PSP sites with a potential of roughly 19 GW were found in Tamil Nadu. Karnataka (8), Madhya Pradesh (9), Mizoram (4), Odisha (8), Rajasthan (9), and Telangana (7) were the other notable states with notable PSP potential. However, 6 of the 10 PSP locations in Mizoram that have been identified are unexploitable since they are not practical (CEA, 2023a).

[102] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/08/PSP_In_Operation.pdf

[103] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/08/PSP_In_Operation.pdf

7.4 STATUS OF ONGOING PSP DEVELOPMENT IN INDIA

According to the CEA's report on PSP development in India as of Oct. 2025[104], there are already 197 PSP sites in various phases of development or in operation. The combined installed capacity of these PSP projects is approximately 223 GW. Table 7.2 and Figure 7.1 show that 132 PSP sites are off-river, with a total installed capacity of about 165 GW, while 65 sites are on-river, with a total installed capacity of approximately 58 GW. Annexure 4 provides a site-by-site detailed table that displays the existing PSP potential. In India, 10 projects totaling 6,685.60 MW of installed capacity were built as pumped storage projects; however, two schemes—Kadana (240 MW) and Sardar Sarovar (1,200 MW)—are currently not operating in pumping mode (CEA, 2025).

The status of ongoing PSP projects is undergoing changes dynamically in various development stages in the country, as several new sites are being identified by different stakeholders and are processed for development in due course. Out of the total PSP sites, 65 sites are located on-river, whereas the majority of sites—132 in number—are off-river. The data presented in Table 7.2 and Figure 7.1 is based on the Oct. 2025 status report available from the CEA.

Table 7.2: Status of ongoing PSP Development in India (As on Oct. 2025) [105]

Status	On River		Off-River		Total	
	No of Schemes	Installed Capacity (MW)	No of Schemes	Installed Capacity (MW)	No of Schemes	Installed apacity (MW)
In operation	9*	5,745.60	**1**	1,680	10	7,425.60
Under Construction	3	3,850.00	8	8,260.00	11	12,110.00
DPR Concurred by CEA	1	1,000.00	4	5,580.00	5	6,580.00
Under S & I	3	3,000.00	49	70,090.00	52	73,090.00
Yet to be Allotted	20	21,200.00	11	13,380.00	31	34,580.00
In other stages of development; PFR, Preliminary studies, TOR Granted etc	29	23,730	60	66,050.00	89	89,780.00
Total	65	58,525.60	132	1,65,040.00	197	2,23,565.60
* Tehre PSP (1000 MW) Under Active Construction (2 nos of unit)/ In Operation (2 no of units)						

Source: CEA (2025)

[104] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/08/PSP_In_Operation.pdf

[105] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf

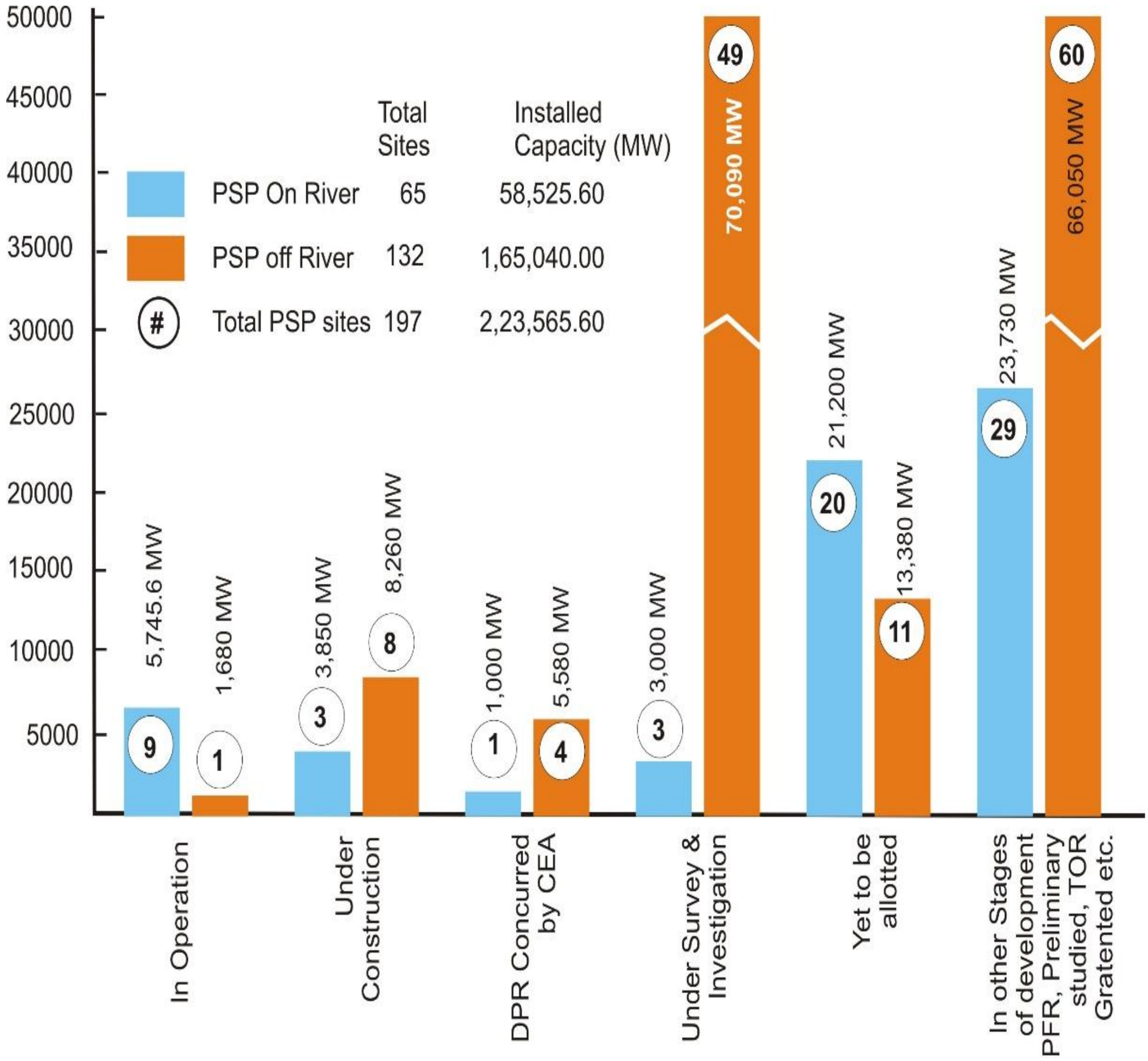
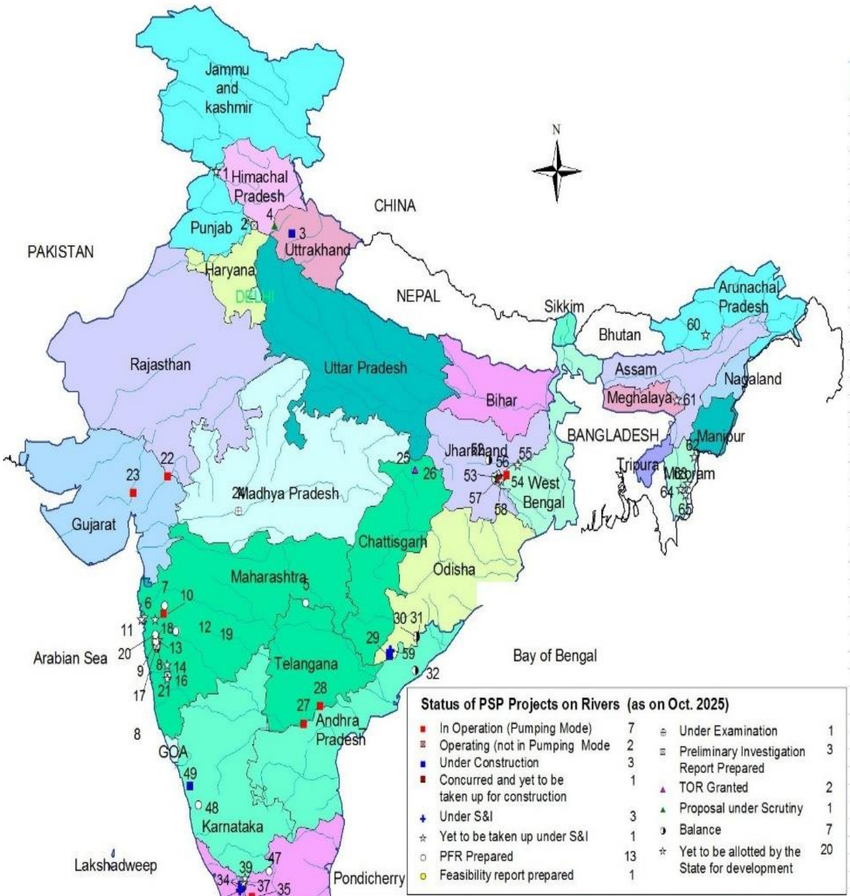


Figure 7.1: Status of ongoing Pumped storage hydropower projects under various stages of Development in India (Status as on Oct. 2025; **CEA, 2025)**

Currently, 11 PSP projects with total installed capacity of 12,110 MW are under construction. At 52 PSP sites with a total capacity of 73,090 MW, survey and investigation is being conducted. Out of these sites 3 site are on River (3,000 MW) and 49 PSP sites are Off-River with a total installed capacity of 70,090.00. (CEA, 2025). Figures 7.2 and 7.3 depict on-river and off-river sites at varying stages of development.



Sno	PSP Name	State	District	Installed capacity (MW)
1	Majra	Himachal	Kangra	700.0
2	Renukaji (Renuka)	Himachal	Sirmaur	1630.0
3	Tehri	Uttrakhand	Tehri Garhwal	1000.0
4	Ichari	Uttrakhand	Dehradun	600.0
5	Ghatghar Stage-II	Maharashtra	Ahmednagar	125.0
6	Malshej Ghat	Maharashtra	Ahmednagar/ Thane	700.0
7	Mutkhel	Maharashtra	Ahmednagar	110.0
8	Warasgaon	Maharashtra	Pune/Raigad	1200.0
9	Bhira	Maharashtra	Raigad	150.0
10	Ghatgar	Maharashtra	Thana	250.0
11	Kengadi	Maharashtra	Thane	1550.0
12	Jalond	Maharashtra	Thane	2400.0
13	Amba	Maharashtra	Pune	800.0
14	Jalvara	Maharashtra	Ratnagiri/Belgaum	2220.0
15	Koyna Left Bank	Maharashtra	Satara	80.0
16	Varandhghat	Maharashtra	Pune	800.0
17	Panshet	Maharashtra	Satara	1600.0
18	Nive	Maharashtra	Pune	1200.0
19	Kodali	Maharashtra	Kolhapur	220.0
20	Atvan	Maharashtra	Pune/raigad	500.0
21	Koyna St-VI	Maharashtra	Satara	400.0
22	Kadana	Gujarat	Panchmahal	240.0
23	Sardar Sarover	Gujarat	Baharuch	1200.0
24	Indira Sagar-Omkareshwar PSP	Madhya Pradesh	Khandwa	640.0
25	Chikni	Chattisgarh	Surajpur	325.0
26	Kharauli	Chattisgarh	Surajpur	500.0
27	Srisailam LBPH	Telangana	Karnool	900.0
28	Nagarjunasagar	Telangana	Nalgonda	705.6
29	Upper Sileru	Andhra pradesh	Vishakhapatnam	1350.0
30	Kurukutti	Andhra pradesh	Vizianagaram	1200.0
31	Karrivalasa	Andhra pradesh	Vizianagaram	1000.0
32	Yerravaram PSP	Andhra pradesh	Vishakhapatnam	1200.0
33	Sillahalla St.-I	Tamilnadu	Nilgiri	1000.0
34	Kundah Pumped Storage (Stage I,II	Tamil Nadu	Nilgiri	500.0
35	Kadamparai	Tamil Nadu	Coimbatore	400.0
36	Kodayar	Tamil Nadu	Kanyakumari	500.0
37	Sandynalla	Tamil Nadu	Nilgiris	1200.0
38	Upper Bhavani	Tamil Nadu	Nilgiris	1000.0
39	Sigur	Tamil Nadu	Nilgiris	800.0
40	Manalar	Tamil Nadu	Theni	1200.0
41	Chattar	Tamil Nadu	kanyakumari	1100.0
42	Karyar	Tamil Nadu	Tirunelveli District	1000.0
43	Aliyar	Tamil Nadu	Coimbatore	700.0
44	Palar-Porathalar	Tamil Nadu	Dindigul	1100.0
45	Athur	Tamil Nadu	Erode	300.0
46	Manjalar	Tamil Nadu	Theni	500.0
47	Mettur	Tamil Nadu	Erode	1000.0
48	Varahi	Karnataka	Dakshina Kannada	1500.0
49	Sharavathy	Karnataka	Shivamonga	2000.0
50	Idukki	Kerala	Idukki	600.0
51	Pallivasal	Kerela	Idukki	600.0
52	Lugupahar	Jharkhand	Bokaro	1500.0
53	Kulbera	West Bengal	Purulia	800.0
54	Bandhu	West Bengal	Purulia	900.0
55	Panchet Hill	West Bengal	Purulia	1000.0
56	Purulia	West Bengal	Purulia	900.0
57	Turga PSS	West Bengal	Purulia	1000.0

Sno	PSP Name	State	District	Installed capacity (MW)
57	Turga PSS	West Bengal	Purulia	1000.0
58	Kathlajal	West Bengal	Purulia	900.0
59	Balimela	Odisha	Malkangiri	500.0
60	Panyor	Arunachal Pradesh	Lower Subansiri	660.0
61	Kopili	Assam	Dima Hasao	320.0
62	Leiva Lui	Mizoram	Aizawl	1500.0
63	Tuiphai Lui	Mizoram	Aizawl	1650.0
64	Nghasih	Mizoram	Lunglai	400.0
65	Daizo Lui	Mizoram	Lunglai	2000.0
			Total	58525.6

Figure 7.2: Status of on–river PSP in India Under Operation and Various Stages of Development

(Source: CEA status Report on PSP, Oct. 2025)

7.4.1 State wise Current Status of PSP under Operation and Various Stages of Development

At present, there are 197 PSP sites in India that are distributed over 21 states and are either operational or in various phases of development; the majority of these sites are found in Andhra Pradesh and Maharashtra. In Andhra Pradesh, 4 PSP sites are on-river with a total of 4,750 MW of installed capacity, and 22 PSP sites are off-river with a total installed capacity of 28,000 MW. Similarly, in Maharashtra, 17 on-river PSP sites with a total of 14,305 MW of installed capacity and 26 off-river PSP sites with an installed capacity of 41,550 MW are in operation or various stages of development. Tables 7.3 and 7.4 present a detailed state-wise list of PSP sites on-river and off-river, respectively, that are under various stages of development or operation (status as of Oct. 20, 2025; CEA, 2025).

Further, on April 3, 2025, the CEA released a list of PSP sites that were granted Terms of Reference (ToR) by the Ministry of Environment, Forest and Climate Change (MoEF&CC) (CEA, 2025[106]). This list shows that the MoEF&CC approved ToR for 103 PSP projects since 2019, totaling 1,24,250 MW of installed capacity. In addition, 3 PSP sites received ToR before 2019 with a total installed capacity of 3,400 MW. According to Annexure 5, these projects are spread throughout 12 states; Andhra Pradesh has a maximum of 21 PSP projects with a total installed capacity of 23,850 MW (Table 22) (CEA, 2025).

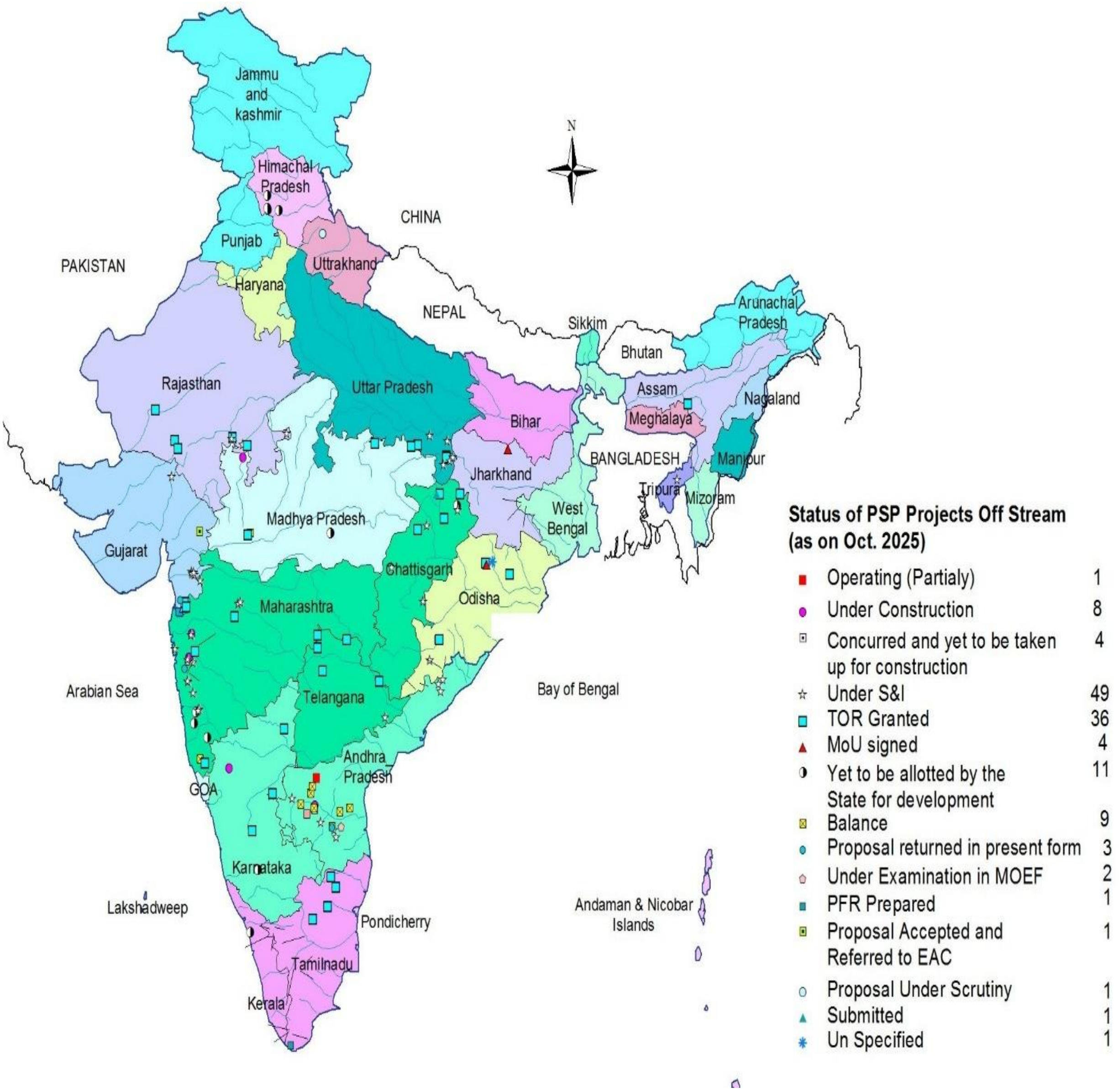


Figure 7.3: Status of off–river PSP in India Under Various Stages of Development
(Source: CEA status Report on PSP, Oct. 2025)

106 https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/04/ToR_granted_to_PSPs_since_2019.pdf

Table 7.3: State Wise On-river PSP Sites Under Operation and Various Stages of Development (Status as on Oct. 2025; CEA, 2025)

Name of State	Operating in Pumping Mode	Not operating in Pumping Mode	DPR Concurred	Under Construction	Under Survey & Investigation	Yet to be Allotted by State for Development	Preliminary Report/ PFR Prepared	Proposal under Scrutiny	TOR Granted	Allotted by state Govt.	Cancelled/ Balance	Total No. of sites	Total Installed Capacity (MW)
Andhra Pradesh				1							3	4	4,750
Arunachal Pradesh						1						1	660
Assam						1						1	320
Chattisgarh									2			2	825
Gujarat	2											2	1,440
Himachal						1	1					2	2,330
Jharkhand					1							1	1,500
Karnataka				1						1		2	3,500
Kerala						2						2	1,200
Madhya Pradesh								1				1	640
Maharashtra	2					6	7				2	17	14,305
Mizoram						4						4	5,550
Odisha					1							1	500
Rajasthan												0	
Tamil Nadu	1			1	1	2	8				2	15	12,300
Telangana	2											2	1,605.6
Uttar Pradesh												0	
Uttarakhand	1							1				2	1,600
West Bengal	1		1			3	1					6	5,500
Total	**9**	**0**	**1**	**3**	**3**	**20**	**17**	**2**	**2**	**1**	**7**	**65**	**58,525.6**

(Source: CEA, 2025; Status as on Oct. 2025)

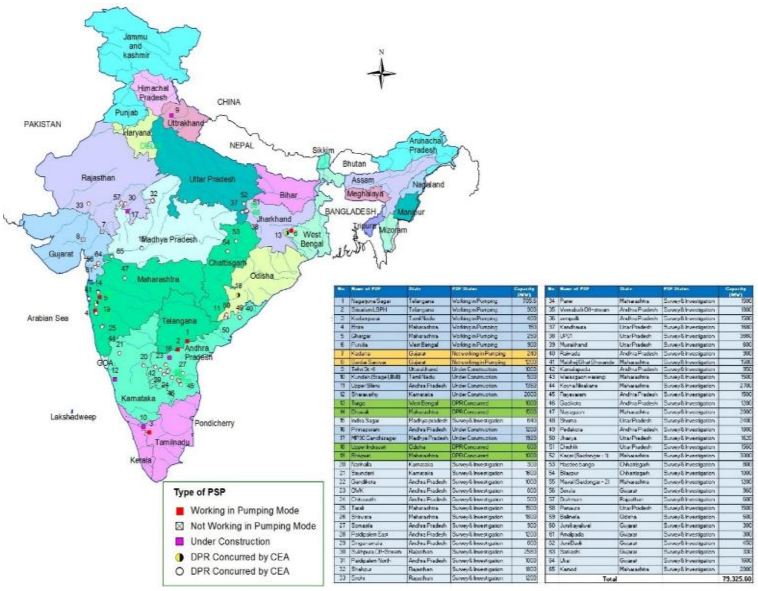


Figure 7.1: Status of PSP Under Operation and Various Stages of Development
(Source: CEA status Report on PSP, Oct. 2025)

Table 7.4: State Wise Status of PSP Sites Off-Stream Under Operation and Various Stages of Development (Status as on Oct. 2025; CEA, 2025)

Name of State	Operating in Pumping Mode	Not operating in Pumping Mode	DPR Concurred	Under Construction	Under Survey & Investigation	Yet to be Allotted by State for Development	Preliminary Report/PFR Prepared	Proposal under Scrutiny	TOR Granted	Allotted by state Govt.	Cancelled/ Balance/ Proposal Returned	Total No. of sites	Total Installed Capacity (MW)
Andhra Pradesh	1			3	8			1			9	22	28,000
Assam									1			1	900
Bihar								3				3	2,480
Chhattisgarh					4	1		1	4			10	11,775
Gujarat					8			1	2		1	12	9,740
Himachal Pradesh						4						4	4,930
Jharkhand												0	0
Karnataka				1	1	1			3			6	4,100
Madhya Pradesh				1		1			4		2	8	9,420
Maharashtra			2	2	13	3		1	3		2	26	41,550
Odisha			1		2			1	3			7	6,415
Rajasthan					4				5			9	12,560
Tamil Nadu					1	1			4			6	7,200
Telangana									5			5	7,150
Tripura					1							1	800
Uttar Pradesh			1		7				3			11	17,620
Uttarakhand								1				1	400
Total	**1**		**4**	**7**	**49**	**11**		**9**	**37**		**14**	**132**	**1,65,040**

(Source: CEA, 2025; Status as on Oct. 2025)

Table 7.4: Summary of ToR Granted for PSP sites by MoEF&CC
(Status as on April 3rd 2025)

State	ToR Granted for PSP Sites by MoEF&CC			
	Since 2019		Before 2019	
	No of PSP Sites	Installed Capacity (MW)	No of PSP Sites	Installed Capacity (MW)
Andhra Pradesh	21	23,850	1	1,200
Chattisgarh	9	9,125		
Gujarat	9	7,540		
Karnataka	5	3,000	1	1,200
Madhya Pradesh	6	6,280		
Maharashtra	16	26,190		
Odisha	6	4,795		
Rajasthan	8	11,000		
Tamil Nadu	7	7,800		
Telangana	5	7,150		
Uttar Pradesh	10	16,620		
West Bengal	1	900	1	1,000
Total	**112**	**1,24,250**	**3**	**3,400**

(Source: CEA, 2025; Status as on April 3rd 2025)

7.4.2 Present Status and Potential of PSP Development in Odisha

With a total operating capacity of 1,968 MW, Odisha has substantial hydropower potential, encompassing both large and minor hydro projects. There are currently 210 dam reservoirs spread across the state (NRLD, 2023). These current dam reservoirs offer the chance to use them as one of the reservoirs and find additional reservoirs in neighboring highland and mountainous areas to construct PSPs.

Odisha is actively developing new hydropower projects, including large-scale pumped storage projects, to increase its hydropower generation capacity. According to (CEA 2025), (status as of Oct. 2025), the estimated PSP potential in Odisha is 6,915 MW, and this potential is through 7 off-stream and 1 on-stream PSP projects[107].

Further, one on-stream PSP (500 MW) is under investigation. For off-stream PSPs, 1 project is concurred, 2 projects are under survey and investigation, for 1 project the proposal is under scrutiny, and for 3 projects, the ToR is granted (CEA, 2025; status as of Oct. 2025).

The following PSP projects are carried out by the state-owned Odisha Hydro Power Corporation (OHPC) and GRIDCO (State Distribution and Transmission Company), which are tasked with assisting the private sector in PSP:

Table 7.5 PSP projects in Odisha for which TOR has been granted

Sl. No.	Project name	District	Installed Capacity (MW)	Type	Company	Date of Grant of TOR
1	OD01	Kalahandi	1200	Off-stream closed stream	Private Sector	17-04-23
2	Tainsar	Deogarh	675	Off-stream closed loop	Private Sector	22-01-24
3	Ramial Left Bank	Keonjhar	1500	Closed loop	Private Sector	15-01-24
4	Upper Kolab	Koraput	320	Open loop	OHPC	28-02-20
5	Balimela	Malkangiri	500	Open loop	OHPC	21-05-20
6	Upper Indravati	Kalahandi	600	Open loop	OHPC	14-12-23
	Total		**4,795**			

Additionally, four PSP projects—the Madhapur project (1000 MW) in Baudh District, the Panabari project (250 MW) in Nayagarh District, and the Kamalakheta (250 MW) and Lakaisuni project (1000 MW) in Ganjam District—are presently being examined for viability and development potential. Before any further action is taken, the technical feasibility, environmental impact, and socioeconomic ramifications of these planned projects are being assessed.

The Nodal Agency and the State Government's SPSUs have identified 45 potential PSP locations, which are already listed on the Nodal Agency website (Table 7.6). These PSP sites

[107] Potential estimation of PSP is undergoing dynamically in the country as several new sites are being identified by different stakeholders. Data presented here are based on Oct.2025 available from CEA.

are recognized as state-identified sites. Additionally, in accordance with the Odisha Pumped Storage Projects (PSP) Policy, the Nodal Agency, SPSUs, CPSUs, or any other State Government agency will continue to search for feasible sites, conduct pre-feasibility studies, and consistently register the projects or sites as identified projects.

Table 7.6 Off stream (open and closed loop) PSP Sites identified by OHPC and GRIDCO

S.No	Name of PSP	District	Lower Reservoir		Upper Reservoir		Capacity (MW)	Identified By
			Latitude	Longitude	Latitude	Longitude		
Off stream open loop								
1	Dandadhar	KEONJHAR	21.1514	85.6126	21.1514	85.6126	900	GRIDCO
2	Deo Dam	MAYUR BHANJ	21.8121	86.0978	21.8213	86.1055	150	GRIDCO
3	Telengiri	KORAPUT	18.9323	82.6588	18.9232	82.6366	650	GRIDCO
4	RET Dam	KALAHANDI	19.9210	83.2724	19.9064	83.2549	450	GRIDCO
5	Brahmani river stream	SUNDAR GARH	22.0346	84.8779	22.0360	84.8931	450	GRIDCO
6	Salandi reservoir	KEONJHAR	21.3137	86.2760	21.3108	86.2498	300	GRIDCO
7	Ghodahada	GANJAM	19.2771	84.4497	19.2585	84.4565	250	GRIDCO
8	Patora Dam	NUAPADA	20.7347	82.4491	20.7381	82.4523	350	GRIDCO
9	Harbhangi	GAJAPATI	19.4949	84.1269	19.5079	84.1082	300	GRIDCO
10	Badanalla stream	RAYAGADA	19.3747	83.9159	19.3611	83.9396	600	GRIDCO
						Total	**4,400**	
Off stream close loop								
11	Koldihi	Deoghar	21.5993	84.5686	21.5874	84.5493	640	OHPC
12	Khunta	Mayurbhanj	21.8430	86.5547	21.8391	86.5236	1000	OHPC
13	Madhapur	Baudha	20.5598	84.6126	20.5419	84.5939	1000	OHPC
14	Tumudibandh	Kandhamal	19.6521	83.9338	20.0176	83.5875	3000	OHPC
15	Ambapani	Kalahandi	19.6380	82.5599	19.6551	82.5483	1000	OHPC
16	Kamalakheta	Gajapati	19.0724	84.3457	19.0848	84.3286	800	OHPC
17	Lakaisunj	Gajapati	18.9515	84.3331	18.9751	84.3443	920	OHPC
18	Prahadipanga	Kandhamal	19.6824	83.9324	19.6676	83.9543	2300	OHPC
19	Panabari	Nayagarh	20.3257	84.7061	20.3441	84.7038	720	OHPC
						Total	**11,380**	
Off Stream Closed loop PSP Site								
20	Kumulsingi	Gajapati	18.9719	84.0889	18.9575	84.0706	750	GRIDCO
21	PSP - 2	Malkangiri	18.6833	82.1700	18.6849	82.1400	3179.32	GRIDCO
22	PSP - 3	Gajapati	19.0197	84.0197	18.9506	84.2678	2379.94	GRIDCO
23	Makod Ghat	Sundergarh	21.8584	84.5633	73.0144	84.5752	300	GRIDCO
24	PSP - 5	Gajapati	19.2519	84.3833	19.3097	84.3606	1157.6	GRIDCO
25	PSP - 6	Kehdujhar	21.5208	85.3708	21.5108	85.3278	1116.84	GRIDCO
26	Barhagarh	Ganjam	19.5850	84.4448	19.5749	84.4161	1000	GRIDCO
27	Sikabadi	Gajapati	19.2514	84.0791	19.2716	84.4161	600	GRIDCO
28	Dhayagurha	Koraput	18.9567	83.2160	18.9556	84.4161	750	GRIDCO
29	PSP - 10	Kalahandi	19.6153	82.5394	19.6450	82.5919	583.18	GRIDCO
30	PSP - 11	Ganjam	19.0681	84.3914	19.1206	84.3883	507.47	GRIDCO
31	PSP - 12	Nayagarh	20.3406	84.6856	20.3622	84.6608	483.66	GRIDCO
32	Dudhapalli	Malkangiri	18.1845	82.2956	18.1790	82.2743	600	GRIDCO
33	PSP - 14	Koraput	18.9631	83.1083	18.9300	83.1131	464.67	GRIDCO
34	Mahughar	Gajapati	19.0659	84.1541	76.4467	84.1393	720	GRIDCO
35	PSP - 16	Kehdujhar	21.4050	85.5317	21.3569	85.4922	366.84	GRIDCO
36	PSP - 17	Malkangiri	18.3153	82.4197	18.3214	82.3439	348.91	GRIDCO
37	PSP - 18	Kandhamal	19.8222	84.1722	19.7875	84.2275	342.39	GRIDCO
38	PSP - 19	Kandhamal	19.9569	84.3503	19.9575	84.4286	298.91	GRIDCO
39	PSP - 20	Sundergarh	22.0128	84.7781	23.0944	84.7847	269.83	GRIDCO
40	Jharigumma	Kalahandi/Nabarangpur	19.5227	82.7231	19.4234	82.6784	500	GRIDCO
41	Bhataguda	Malkangiri	18.3828	82.2253	18.3786	82.2545	720	GRIDCO
42	PSP - 23	Nayagarh	20.3722	84.6933	20.3789	84.6817	228.26	GRIDCO
43	PSP - 24	Malkangiri	18.6878	82.2247	18.6740	82.2180	209.98	GRIDCO

S.No	Name of PSP	District	Lower Reservoir		Upper Reservoir		Capacity (MW)	Identified By
			Latitude	Longitude	Latitude	Longitude		
44	Balinala	Ganjam	19.6025	84.2726	19.5890	84.2778	750	GRIDCO
45	PSP - 26	Malkangiri	18.4550	82.2900	18.4767	82.2181	200.41	GRIDCO
						Total	**18,830**	
						Grand Total	**34,610**	

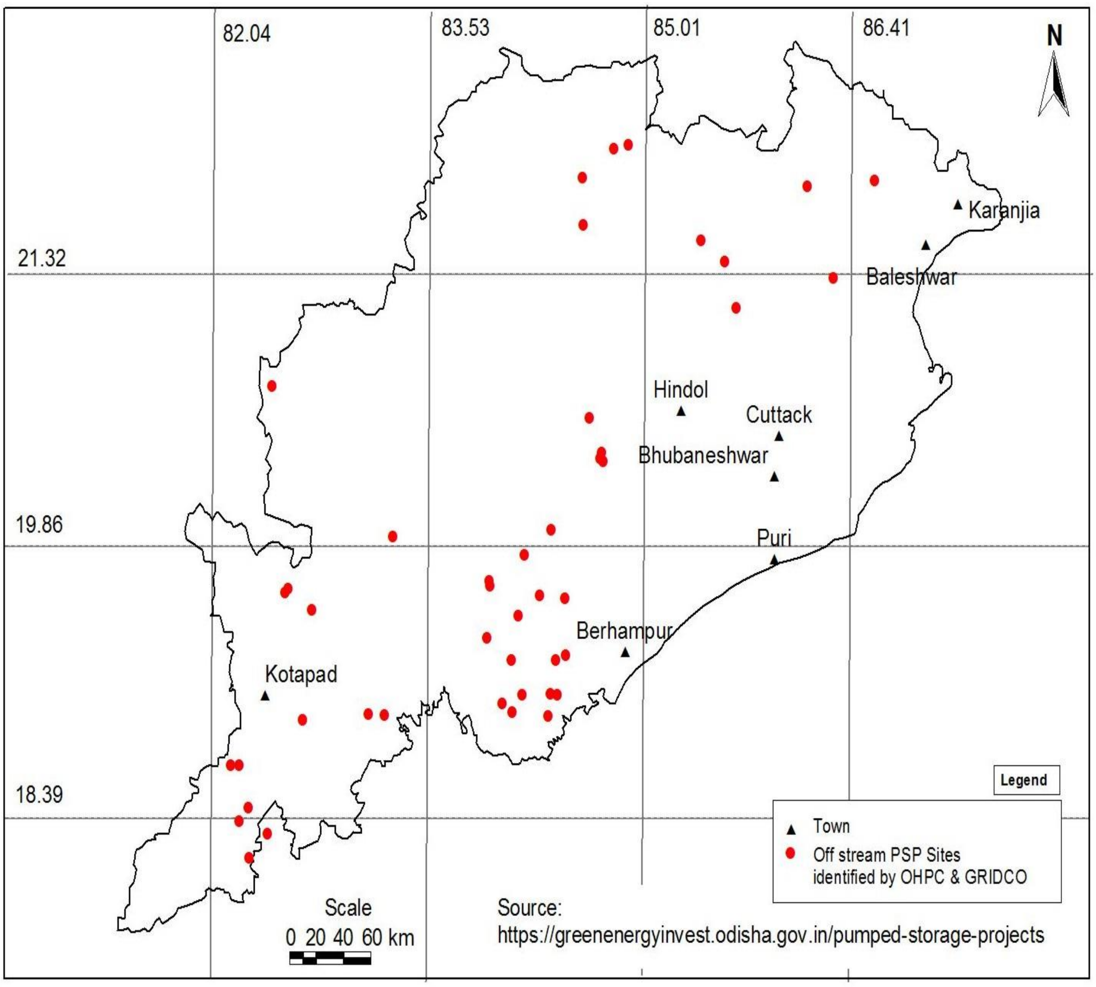


Figure 7.6 Off stream (open and closed loop) PSP Sites identified by OHPC and GRIDCO
(Source: https://greenenergyinvest.odisha.gov.in/pumped-storage-projects/)

7.4.2 PSP Capacity Addition Plan Till 2035 – 36

The country's PSP development is underway and aligned with energy transition plans in relation to India's worldwide responsibilities regarding climate change challenges. The capacity addition plan through 2035–2036 (status as of Oct. 2025; CEA, 2025), which calls for the commissioning of 62 PSP projects with a total installed capacity of almost 83 GW (Table 7.7), clearly shows the progress made in PSP. Energy storage capacity from PSP through 2026–2027 is projected to be 7.45 GW in the National Electricity Plan (NEP), 2023 (MoP, 2023).

Table 7.7 PSP Capacity Addition Plan Till 2035 – 36 (CEA, 2025; Status Oct. 2025) [108]

Year	Total IC (MW)	S. No.	Name of Project	State	IC (MW)	Developer	Stage
2025-26	2,680	1	Pinnapuram	Andhra Pradesh	1680	Greenko	Under Construction (7 units commissioned total 1440MW)
		2	Tehri PSS	Uttarakhand	1000	THDC	Under Construction (2 Units Commissioned total 500 MW)
2026-27	2,920	1	Kundah PSP PhI,II & III	Tamilnadu	500	TANGEDCO	Under Construction
		2	MP 30 Gandhi Sagar	Madhya Pradesh	1920	Greenko	Under Construction
		3	Chitravathi	Andhra Pradesh	500	Adani Green	Under Construction
2027-28	1,600	1	Saundatti	Karnataka	1600	Greenko	Under Construction
2028-29	6,350	1	Upper Sileru	Andhra Pradesh	1350	APGENCO	Under Construction
		2	Bhivpuri	Maharashtra	1000	Tata Power	Under Construction
		3	Bhavali	Maharashtra	1500	JSW Energy	Under Construction
		4	Gandikota	Andhra Pradesh	1000	Adani Green	Under Constuction
		5	Tarali	Maharashtra	1500	Adani Green	S&I
2029-30	13,500	1	Kandhaura	Uttar Pradesh	1680	JSW Energy	Concurred by CEA and yet to be taken up for construction
		2	UP01	Uttar Pradesh	3660	Greenko	S&I
		3	Chichlik	Uttar Pradesh	1560	Avaada	S&I
		4	Sirohi	Rajasthan	1200	JSW Energy	S&I
		5	Narihalla	Karnataka	300	JSW Energy	S&I
		6	Nayagaon	Maharashtra	2000	Greenko	S&I
		7	Panaura	Uttar Pradesh	1500	Adani Green	S&I
		8	Ukai	Gujarat	1600	Greenko	S&I
2030-31	21,190	1	Shahpur	Rajasthan	1800	Greenko	S&I
		2	Bilaspur	Chhattisgarh	1000	Jindal Renewables	S&I
		3	Pane	Maharashtra	1500	JSW Energy	Concurred by CEA and yet to be taken up for construction
		4	Malshejghat Bhorende	Maharashtra	1500	Adani Green	S&I
		5	Warasgaon Warangi	Maharashtra	1500	Adani Green	S&I
		6	Raiwada	Andhra Pradesh	900	Adani Green	S&I
		7	Kamalapadu	Andhra Pradesh	950	APGENCO	S&I
		8	Shirawta	Maharashtra	1800	Tata Power	Concurred by CEA and yet to be taken up for construction
		9	Saidongar 1 - Karjat	Maharashtra	3000	Torrent PSH 4 Pvt. Ltd.	S&I
		10	Indira Sagar	Madhya Pradesh	640	NHDC	DPR submitted & under examination

[108] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_capacity_addition.pdf

Year	Total IC (MW)	S. No.	Name of Project	State	IC (MW)	Developer	Stage
		11	Vempalli	Andhra Pradesh	1500	JSW energy	S&I
		12	Shoma	Uttar Pradesh	2400	Torrent PSH 1 Pvt. Ltd.	S&I
		13	Koyna Nivakane	Maharashtra	2700	Adani Green	S&I
2031-32	8,800	1	Kamod	Maharashtra	2000	Megha Engineering	S&I
		2	Ghosla	Maharashtra	2000	Megha Engineering	S&I
		3	Pedakota	Andhra Pradesh	1800	Adani Green	S&I
		4	Upper Bhavani	Tamilnadu	1000	NTECL	S&I
		5	Masinta	Odisha	1000	NHPC	S&I
		6	Turga	West Bengal	1000	WBSEDCL	Concurred by CEA and yet to be taken up for construction
2032-33	13,740	1	Upper Indravati	Odisha	500	OHPC	Concurred by CEA and yet to be taken up for construction
		2	Sharavathy	Karnataka	2000	KPCL	Under Construction
		3	Musakhanda	Uttar Pradesh	600	ACME	S&I
		4	Sukhpura	Rajasthan	2560	Greenko	S&I
		5	Serula	Gujarat	960	GSECL	S&I
		6	Dharoi	Gujarat	500	GSECL	S&I
		7	Saidongar 2 - Maval	Maharashtra	1200	Torrent PSH 4 Pvt. Ltd.	S&I
		8	Jhariya	Uttar Pradesh	1620	Jhariya Anant Urja	S&I
		9	Rayavaram	Andhra Pradesh	1500	APGENCO & ONGC	S&I
		10	Brahmani	Rajasthan	600	ACME Urja Two Pvt. Ltd.	S&I
		11	Balimela	Odisha	500	OHPC	S&I
		12	Gadikota	Andhra Pradesh	1200	APGENCO & NHPC	S&I
2033-34	11,880	1	Juni Kayaliwel	Gujarat	300	GSECL	S&I
		2	Amalpada	Gujarat	300	GSECL	S&I
		3	Juni Bavli	Gujarat	450	GSECL	S&I
		4	Satkashi	Gujarat	330	GSECL	S&I
		5	Upper Kolab	Odisha	600	OHPC	S&I
		6	Savitri	Maharashtra	2400	NHPC	S&I
		7	Hasdeo Bango	Chhattisgarh	800	CSPGCL	S&I
		8	Sikaser	Chhattisgarh	1200	CSPGCL	S&I
		9	Rouni	Chhattisgarh	2100	CSPGCL	S&I
		10	Kalu Patti	Uttar Pradesh	1000	Renew Hydro	S&I
		11	Pawana Falyan	Maharashtra	2400	Avaada	S&I
Grand Total	**82,660**						

Source: CEA, 2025 (Status as on Oct. 2025) https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_capacity_addition.pdf

Furthermore, PSP projects with a sizable capacity are planned for commissioning virtually annually. Six PSP projects with a combined capacity of 7,200 MW will be put into service up to 2027–2028, and 5 PSP projects with a combined capacity of 6,350 MW will be put into service during 2028–29. Additionally, 8 PSP projects with a combined installed capacity of 13,500 MW will be built in 2029–2030; thirteen PSP projects with a combined installed capacity of 21,190 MW will be created in 2030–31; and 6 PSP projects with a 8,800 MW capacity will be developed in 2031–2032 (CEA, 2025)[109]. During 2032–33, 12 PSP projects with a total capacity of 13,740 MW are planned to be constructed. Later, during 2033–34, a total of 11 PSP projects with a total capacity of 11,880 MW are planned. Last but not least, NEP 2023 projects that the PSP will need 26.69 GW by 2031–2032. Additionally, according to the PSP capacity increase plan, the capacity will reach roughly 83 GW by 2033–2034 (MoP, 2023; CEA, 2025).

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[109] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_capacity_addition.pdf

CHAPTER 8: INSTITUTIONAL FRAMEWORK FOR PSP DEVELOPMENT IN INDIA

8.1 INSTITUTIONAL FRAMEWORK

Government agencies and several stakeholders are involved in the development and operation of PSP projects in India. Each of them has a distinct role to play at different phases, beginning with project planning, approvals, funding, execution, operation, and maintenance. Government organizations in charge of formulating policies, approving and overseeing agencies, regulators, investors and financiers, grid operators, developers, and other related organizations are the main institutions and stakeholders. Table 8.1 provides an overview of the organizations and different stakeholders in charge of PSP project creation and management.

Table 8.1: Principal Organizations and Participants in the Development and Function of PSP in India

Ministry of Power (MoP)

(i) The Ministry of Power is primarily in charge of developing and carrying out energy-related policies. Guidelines for the encouragement of PSP development are included in the policies and regulatory framework.

(ii). Incentives and support for development of PSP (MOP, 2024a).

Ministry of Environment, Forest and Climate Change (MoEF&CC)/ State Environment Departments

(i) In accordance with the Environment (Protection) Act of 1986 and the EIA Notification of 2006, it is responsible for providing Environmental Clearance (EC) to PSP projects..

(ii) To grant the PSP Project clearance for forests and wildlife in accordance with the Wildlife (Protection) Acts of 1972 and 1993 (MoEF&CC, 2024a)

Central Electricity Authority (CEA)

(i) By providing technical support base to all stakeholders in the PSP sector, CEA perform its statutory function

(ii) CEA supports Ministry of Power in formulating policies in the PSP sector.

(iii) CEA prepares technical standards & regulations, to carry out project monitoring

(iv) CEA is responsible for approval of DPR of PSP projects.

(v) For supply of electricity CEA provides technical standards for grid connectivity (CEA, 2024g)

Central Electricity Regulatory Commission (CERC)

(i) CERC regulates the tariff of generating plants.

(ii) CERC regulates the inter-State transmission of electricity

(iii) It determines tariff for inter-State transmission of electricity.

(iv) It forms regulations for Ancillary Services of PSP Operations (CERC, 2024).

State Electricity Regulatory Commissions (SERC)

(i) Within the State, SERC establishes the tariff for electricity generation, supply, transmission, and wheeling, as well as for entire, bulk, and retail sales..

(ii) It issues licenses for intra-State transmission, distribution and trading.

(iii) It promotes co-generation and generation of electricity from RE sources of energy etc (MoP)

(iv) SERC forms Regulations for Ancillary Services of PSP Operations within respective state.

National Load Dispatch Center (NLDC) / Power System Operation Corporation (POSOCO)

(i) Responsible to dispatch and schedule electricity over inter regional network.

(ii) NLDC/ POSOCO facilitates smooth operation of regional and national power systems

(iii) It monitor operations and grid security of the National Grid

(iv) It coordinate with RLDCs

(v) Performance monitoring and energy accounting of system.

(vi) It charge beneficiaries for providing services

Regional Load Dispatch Center (RLDC)

(i) In charge of the best scheduling and distribution of energy in the area in compliance with the agreements made with the licensees or generating firms (in this case, PSP) who operate there.

(ii) Responsible to Integrate PSPs and including them for planning purpose at the regional level

(iii) Monitors grid operations (NRLD).

State Load Dispatch Center (SLDC)

(i) It is responsible for optimum scheduling and dispatch of electricity within a State in accordance with the contracts entered into with the licensees or the generating Companies (PSPs in this case) operating in that State.

(ii) Monitoring grid operation.

(iii) Responsible to integrate PSPs and including them for planning purpose at the State level

(iv) Keep accounts of the quantity of electricity transmitted through State grid (NRLD).

Transco (Transmission Companies)- CTU/ STU

(i) Responsible to undertake transmission of electricity through inter-State transmission system

(ii) To discharge all functions of planning and co-ordination relating to inter-state transmission system with - STU, Central Government, State Governments, generating companies (PSP in this case), RPC, licensees etc

(iii) To ensure development of an **efficient**, co-ordinated and economical system of inter-State transmission lines for smooth flow of electricity from generating stations (PSP in this case) to the load centres (MoP_CTU)

Discoms (Distribution companies)

Facilitate with distribution of power to consumers

It procures power from PSP and other generating sources

Responsible to purchase power from generating unit (PSP)

Financial institutions

They provide funds for the development of project.

Financial institutions like PFC, REC, and IREDA can provide long-term loans

As per CEA Guideline (CEA, 2023c) Financial institutions like PFC, REC, and IREDA shall treat PSPS at par with other RE projects while extending long term loans of 20-25 years tenure. The debt equity ratio of PSP projects can be up to 80:20, in consultation with the financial institutions (CEA, 2023c).

PSP Developers

Responsible to identify, plan and develop techno - economically feasible PSP project

Conduct site appraisal for its suitability to develop safe project

To secure funding for development of project

Prepare DPR and seek approvals for various clearances from central and state Governments

Develop project with approved design and commissioning as per schedule.

Operate project as per requirements during off peak and peak demands and extend ancillary services for Grid stability.

Maintain project for safe and uninterrupted performance.

Engineering, Procurement, and Construction (EPC) Agencies

Responsible for project management

Engineering design,

Procurement of materials, and

Construction activities

Survey and Investigating agencies

Responsible for quality surveys and investigations

Speedy and quality geological investigations

Speedy geotechnical investigations with required values

Availability of water and power evacuation facilities.

Consultants

Responsible for reports preparation

Responsible for engineering design as per Indian and International code of practices

Specifications for construction and supply

Quality monitoring and supervision.

Source: MOP (2024a); MoEF&CC (2024a); CEA (2024g); CERC (2024); NRLD; MoP_CTU; MoP_CTU

8.2 STATUTORY PROCEDURE FOR THE DEVELOPMENT OF PSP

Any generating company planning to establish a hydro generating station must prepare and submit a proposal to the Authority for approval in accordance with Section 8(1) of the Electricity Act, 2003. According to Section 8(2) of the Electricity Act of 2003, the Authority must consider, whether or not it agrees with, the following factors before approving any project that is submitted to it:

(i) The proposed river works: For the best possible development of the river or its tributaries for the generation of electricity, it needs to be in accordance with the needs of drinking water, irrigation, navigation, flood control, or other public purposes. The Authority will be satisfied with this if a sufficient study has been conducted on the best locations to place dams and other river works.

(ii) Compliance with safety and design: The suggested plan complies with safety and design standards for dams.

According to Section 8(3) of the Electricity Act of 2003, the State Government and the generating company must coordinate their activities with those of the people in charge of the multipurpose scheme for the development of any river in any region, to the extent that they are related.

In-principle Allotment/MoU/MoA for the execution of any PSP scheme by the State Government to a Generating Company/Project Developer shall be immediately intimated to the CEA by the State Government. Approval of the ToR from the MoEF&CC for any PSP scheme by the MoEF&CC to a Generating Company/Project Developer shall be immediately intimated to the CEA by the project developer. If such an allotted project is to be concurred by the CEA under Section 8 of the Electricity Act, 2003, in such a case, the concerned Generating Company/Project Developer shall approach the CEA within a month. Also, if the project is to be concurred by the State Government, in such a case, the State Government shall send a letter of concurrence to the CEA after concurrence of the DPR of the project.

For PSP development, the project developer must complete a number of pre-defined activities. The following is a chronological list of such activities:

1. No Objection Certificate (NOC) from the State Forest Department.
2. Hydrological Studies:
    - Setting up gauge and discharge site
    - Hydrological data collection
    - Preliminary assessment of water availability
    - Preliminary assessment of design flood estimation
    - Submission of hydrological report

  - Preliminary assessment of power potential
  - Submission of power potential studies
  - E&M sizing and finalization of layout
3. Geological / Geotechnical Investigations:
  - Topographic survey and surface mapping (for dams and PH)
  - Discussion with CEA, CWC, CSMRS, and GSI for investigation; desk studies and identification of alternatives
  - Consult with CEA, CWC, CSMRS, and GSI to finalize investigations
  - Final investigation Phase – II
  - Submission of geological reports
4. Submission of hydro-civil layout and broad salient features
5. Basin-specific studies for in-stream projects
6. Seismicity and field investigations report submission:
  - Submission of report/proposal for site-specific seismic design parameters
7. Construction material investigations:
  - Construction material survey and investigations – Phase I
  - Construction material testing and rock testing – Phase I
  - Construction material survey and investigations – Phase II
  - Construction material testing and rock testing – Phase II
  - Submission of material testing reports
8. Submission of MoWR and interstate-related matters
9. Preparation of DPR (Detailed Project Report)

Additionally, before PSP construction can begin, the project developer needs to obtain a number of permissions (Table 25). As part of its efforts to shorten the clearance time, the CEA issued recommendations for DPR preparation and acceptance for PSP in June 2024. The following are important actions taken to hasten PSP development in India:

If it is realized that the PSP is technically and economically viable with the necessary inputs/clearances having been tied up, the Authority may accord concurrence for the implementation of the PSP scheme, as far as practicable, within a period of 50 (fifty) days (excluding time taken by the developer for compliance with observations of CEA/CWC/ GSI/CSMRS, etc.) from the date of submission of 8 sets of DPR complete in all respects, or the acceptance of the complete DPR by the CEA from the developer for:

1. PSPs awarded under Section 63 of the Electricity Act, 2003 (determination of tariff by bidding process).
2. PSPs which are part of Integrated Renewable Energy Projects that contain other renewable energy sources such as wind energy, solar energy, etc.

Table 8.2: Type of Clearances Required for PSP Development in India

Sl. No.	Type of clearances	Issuing Authority	Reason for its requirement	Procedure
I	Land	State Government	To ensure land availability	Application is submitted to the concerned State Revenue Department for land acquisition as per requirement of project.
II	Water	State Government / CWC	To ensure water ailability and free om any dispute	Application is submitted to State Water Resource Department.
III	Comfort letter from Beneficiaries	Concerned Discom/exchanges	Willingness of Discom/exchanges to buy power.	Letters sent to Discom/exchanges/successor entities for giving their consent to buy power.
IV	Forest clearance (if applicable)	MOEFCC/ State Government	This is required as per law.	Application is submitted to State Government for onward submission to MOEFCC in case forest land is to be acquired by the project. Presently it is issued in two stages, first in-principal and once conditions stipulated are complied then formal clearance.
V	Defence clearances (for project located in proximity to International Border, LOC, restricted area, etc.)	Defence Authority	This is required as per law.	Application giving location and other details is submitted to MoP for taking up the matter with Ministry of Defence for Defence Clearance.
VI	Clearance for inter-state & international angle (if applicable)	MOJS/ CWC	This is required as per law.	Request is submitted to MoP for obtaining this clearance from MOJS.
VII	Clearances from Archeological Survey of India (ASI) (if applicable)	ASI	This is required as per citing criteria of MOEFCC	Application is submitted to Archeological Survey of India indicating location of project and other details for seeking NOC.
VIII	Preparation of Detailed Project Report	Chairman/ Board of Directors	As per guidelines of CEA, DPR is prepared for implementation of the project	DPR is prepared by the project in association with all the concerned divisions of Corporate Office.
IX	Concurrence of the scheme (earlier called Techno- economic clearance)	Central Electricity Authority	Electricity Act, 2003 (amended from time to time)	The DPR is submitted to CEA for Concurrence of the scheme (earlier Techno-economic clearance).
X	Approval of Terms of Reference (TOR) along with the clearance for pre-construction activities from MOEFCC	MOEFCC	Approval of TOR and for pre-construction activities from MOEF is required under EIA Notification 2006	Filing of Application with filled in Form I along with a copy of PFR and draft TOR for undertaking EIA & EMP study to MOEF.
XI	Public Hearing by State Pollution Control Board (SPCB)	SPCB	Public Hearing is required under EIA Notification 2006	Application along with draft EIA & EMP reports and its executive summary in English and local language are to be submitted. SPCB to issue a notice in two local newspapers for public hearing.

Sl. No.	Type of clearances	Issuing Authority	Reason for its requirement	Procedure
XII	Environment clearance	MOEFCC	Obtaining environmental clearance is required under the Act.	Final EIA & EMP reports incorporating comments received during Public consultation process is to be submitted to MOEFCC. The proposal is referred to Expert Appraisal Committee.
XIII	Investment approval	CCEA	Hydro projects are approved by CCEA, GoI	Investment proposal is submitted by MoP to PIB for its recommendation and thereafter to CCEA for sanction.

- Within a period of 50 (fifty) days (excluding time taken by the Developer for compliance of observations of CEA/ CWC/ GSI/ CSMRS etc.) from the date of submission of 8 sets of DPR complete in all respects/ acceptance of Complete DPR by CEA from Developer for Pumped Storage Schemes.
- special dispensation is required for concurrence of DPRs of Pumped Storage projects.

8.3 PUBLIC AND PRIVATE SECTOR PARTICIPATION IN PSP DEVELOPMENT IN INDIA

In recent times, private and public sector developers have been showing interest and motivation in PSP development due to current developments in various policies and initiatives implemented for PSPs by the Central Government and some State Governments. Currently, approximately 35 private companies are involved in PSP development (Table 8.3), with three of these companies—Greenko, Adani Green Energy Limited, and JSW Energy Ltd.—developing approximately 32 PSP sites.

Fifteen PSP sites totaling approximately 26.63 GW of installed capacity are being developed by Greenko in 11 states. Adani Green Energy Limited is developing 11 PSP sites with a total of 15.6 GW of capacity in 5 states. Similarly, JSW Energy Ltd. is developing 6 PSP sites with a total installed capacity of 6.31 GW in 5 states. Table 8.3 presents public and private sector involvement in PSP development in the country.

Table 8.3: Public and private Sector Involvement in PSP Development in India

	Promoter/Developer	No. of Sites	nstalled capacity (MW)	Andhra Pradesh	Arunachal Pradesh	Assam	Bihar	Chhattisgarh	Gujarat	Himachal Pradesh	Jharkhand	Karnataka	Kerala	Madhya Pradesh	Maharashtra	Mizoram	Odisha	Rajasthan	Tamilnadu	Telangana	Tripura	Uttar Pradesh	Uttarakhand	West Bengal
Public Sector	Andhra Pradesh Power Generation Corporation Ltd (APGENCO)	5	5820	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Andhra Pradesh Power Generation Corporation Ltd (APGENCO) & Oil and Natural Gas Corporation (ONGC)	1	1500	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bhakra Beas Management Board (BBMB)	3	3050	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Chhattisgarh State Power Generation Company Ltd (CSPGCL)	5	7300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Damodar Valley Corporation (DVC)	4	4300	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
	Gujarat State Electricity Corporation Ltd (GSECL)	9	4580	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Himachal Pradesh Power Corporation Ltd. (HPPCL)	1	1630	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Karnataka Power Corporation Ltd (KPCL)	2	3500	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Maharashtra State Power Generation Company (MAHAGENCO)	1	250	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Narmada Hydroelectric Development Corporation (NHDC)	2	1440	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
	National Hydroelectric Power Corporation (NHPC)	7	10950	0	0	0	0	0	0	0	0	0	0	1	4	0	1	0	0	0	1	0	0	0
	National Thermal Power Corporation (NTPC)	8	9400	0	0	0	0	0	0	1	0	1	0	0	3	0	0	0	3	0	0	0	0	0
	New & Renewable Energy Development Corporation of Andhra Pradesh Ltd (NREDCAP)	2	1550	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	North Eastern Electric Power Corporation Ltd (NEEPCO)	6	6530	0	1	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
	NTECL	1	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

	Promoter/Developer	**No. of Sites**	Installed capacity (MW)	Andhra Pradesh	Arunachal Pradesh	Assam	Bihar	Chhattisgarh	Gujarat	Himachal Pradesh	Jharkhand	Karnataka	Kerala	Madhya Pradesh	Maharashtra	Mizoram	Odisha	Rajasthan	Tamilnadu	Telangana	Tripura	Uttar Pradesh	Uttarakhand	West Bengal
	Odisha Hydro Power Corporation Ltd (OHPC)	3	1700	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
	Sardar Sarovar Narmada Nigam Ltd (SSNNL)	1	1200	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Satluj Jal Vidyut Nigam Ltd (SJVNL)	2	2400	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Tamil Nadu Generation and Distribution Corporation Ltd (TANGEDCO)	5	3100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
	TANGEDCO + TATA Consultancy energy	7	6100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0
	TANGEDCO + Tractbel Pvt Ltd	1	1200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Tehri Hydro Development Corporation Ltd (THDC)	2	2000	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
	Telangana State Power Generation Corporation Ltd (TSGENCO)	2	1605.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
	THDC India Ltd (THDCIL)	4	3850	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0
	UJVN Ltd	2	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
	Water Resources Department (WRD), Maharashtra	10	6235	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	West Bengal State Electricity Distribution Company Ltd (WBSEDCL)	4	3700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
	SUB TOTAL (Public Sector)	100	96891																					
Private Sector	ACME Urja Two Private Ltd.	2	1200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
Private Sector	Adani Green Energy Ltd	9	13600	3	0	0	0	0	1	0	0	0	0	0	3	0	0	1	0	0	0	1	0	0
Private Sector	Adani Hydro Energy Pvt Ltd	1	1500	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Private Sector	Adani Renewable Energy Forty-Two Ltd	1	500	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Private Sector	Astha Green Energy Ventures India Private Ltd	4	4240	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0

Promoter/Developer	No. of Sites	nstalled capacity (MW)	Andhra Pradesh	Arunachal Pradesh	Assam	Bihar	Chhattisgarh	Gujarat	Himachal Pradesh	Jharkhand	Karnataka	Kerala	Madhya Pradesh	Maharashtra	Mizoram	Odisha	Rajasthan	Tamilnadu	Telangana	Tripura	Uttar Pradesh	Uttarakhand	West Bengal
Avaada Aqua Batteries Private Ltd	3	5520	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0
Cerulean Energy Solutions Private Ltd	3	1210	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0
Chikni Energy Private Ltd	1	325	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eco Leap Technologies India private Ltd	1	2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Gandhwani Energy Private Ltd	1	1200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Greenko	15	26630	1	0	1	0	0	1	0	0	1	0	1	2	0	1	2	2	2	0	1	0	0
GSC PSP Madhya Pvt Ltd	1	1500	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Hunduja Renewable Energy Ltd	1	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indosol Solar Power Pvt. Ltd.	2	2200	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jhariya Anant Urja	1	1620	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Jindal Renewable Power Private Ltd	2	1515	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
JSW Energy	6	6310	1	0	0	0	0	0	0	0	2	0	0	1	0	0	1	0	0	0	1	0	0
Kharauli Energy Private Ltd	1	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Megha Engineering	2	4000	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
NECL	2	4200	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOT AVAILABLE	5	9300	1	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0
NREDCAP & AGEL	3	3000	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Renew	4	4000	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1	0	0
Rithwik Projects Private Ltd	2	1800	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
RVR Project Pvt Ltd	1	800	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sasa Stone Private Ltd	2	1240	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Semaliya Energy Private Ltd	1	1200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Shirdi Sai Electricals Ltd.	2	2100	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Promoter/Developer	No. of Sites	Installed capacity (MW)	Andhra Pradesh	Arunachal Pradesh	Assam	Bihar	Chhattisgarh	Gujarat	Himachal Pradesh	Jharkhand	Karnataka	Kerala	Madhya Pradesh	Maharashtra	Mizoram	Odisha	Rajasthan	Tamilnadu	Telangana	Tripura	Uttar Pradesh	Uttarakhand	West Bengal
	Sri Siddharth Infratech & Services (I) Private Ltd	3	4200	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0
	Sterlite Grid 36 Ltd	1	1200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sun Petrochemicals Pvt Ltd	3	2480	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tata Power	3	2950	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
	Torrent Power	6	10660	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0
	Venika Green Power Private Ltd	1	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Volthills Private Ltd	1	900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Sub total (Private Sector)	**97**	**126,675**																					
	Total (Public + Private Sector)	197	223,566																					

(Source: CEA, 2025; Status Oct. 2025; https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf

Under Greenko, three projects are under construction, namely: Pinnapuram (1680 MW)—under construction (1 unit) / in operation (7 units), MP30 Gandhisagar (1920 MW), and Sauundatti (1600 MW). Another five projects with a total installed capacity of 11,620 MW are under survey and investigation. Under Greenko, for seven projects with a total installed capacity of 9,810 MW, the ToR is granted. Similarly, under Adani Green Energy Ltd., two projects, namely Gandikota (1,000 MW) and Chitravati (500 MW) in Andhra Pradesh, are under construction. Further, five projects with a total capacity of 7,200 MW are under survey and investigation.

The majority of the other private enterprises have one or two PSP sites each, and they are in different stages of development (CEA, 2025; status Oct. 2025) [110].

Moreover, public sector CPSUs/State PSUs comprise 100 PSP sites with an installed capacity of approximately 96.89 GW. These comprise five PSP facilities that are now in operation, while the other 95 PSP sites are in various phases of development. With nine PSP sites, Gujarat State Electricity Corporation Limited (GSECL) has 4.58 GW of installed capacity overall. Among these projects, Kadana (240 MW) in Gujarat is presently not working in pumping mode, and the remaining eight projects are under survey and investigation. Similarly, five PSP projects with a total installed capacity of 7.3 GW in Chhattisgarh are being developed by Chhattisgarh State Power Generation Company Limited. Presently, these projects are under various stages of development.

The Ministry of Power has assigned central power generating PSUs—primarily NHPC Ltd, NTPC, NEEPCO, SJVN Ltd, THDC Ltd, and BBMB—to promote and expedite the public sector's development of PSP. Preparatory work has also been started by the majority of state power generating PSUs, including TANGEDCO, CSPGCL, WRD Maharashtra, OHPC, HPPCL, KPCL, WBPDCL, and APPGCL, in order to create PSPs.

It is anticipated that the private sector participants will contribute the required funds and technological know-how, including foreign partners, for quick, affordable construction and extensive operation in order to quickly create large-scale PSPs. The private sector may also have the advantage of quick decision-making to prevent delays and overspending, close collaboration with technical and financial consultants, and quicker contractor payments to lower project costs and accelerate development.

According to the current PSP development status report by the CEA (Oct. 2025), public sector organizations are linked to operate and develop 96.89 GW of PSP potential through 100 PSP sites, whereas private enterprises are now involved in developing 126 GW (97 PSP sites) of PSP potential (CEA, 2025). This demonstrates that, in terms of capacity, PSP development in the private sector is currently accelerated and gradually catching up with the public sector.

Since the Government of India, in its decision dated August 8, 2022, has designated PSP sites against various CPSUs to facilitate their development, more PSP sites would soon be taken up for development by the public sector's CPSUs. A total of 55 PSP sites have been recommended

[110] https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf

to different CPSUs, with an installed capacity of roughly 73 GW. State governments are urged to assign PSP sites to CPSUs for early development in their states (CEA, 2023c). Annexure 6 lists the specifics of the new PSP projects that are currently being developed.

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CHAPTER 9: SUPPORTING POLICIES AND REGULATIONS FOR PSP DEVELOPMENT IN INDIA

9.1 OVERVIEW

During recent years, the Central Government and some State Governments have formulated and implemented supportive policies, regulations, and initiatives to promote PSP development in the country. These measures have attracted the attention and motivation of both private and public sector developers. Furthermore, with such a positive approach, the development of PSP in the country is being accelerated.

9.2 THE EXISTING POLICY FRAMEWORK FOR PSP - NATIONAL FRAMEWORK FOR PROMOTING ENERGY STORAGE SYSTEMS (ESS/ PSP)

In order to promote PSP in the country, the Ministry of Power announced a National Framework for Promoting Energy Storage Systems (ESS/PSP) in Aug 2023. The main objectives of this framework that enable and promote PSP development are discussed in the following paragraphs. Figure 9.1 displays the objectives of the national framework.

(i) Energy Storage Obligation (ESO): A long-term trajectory for ESO has been communicated in order to guarantee the availability of adequate storage capacity. Through ESS, a distribution licensee's territory must obtain a minimum percentage of its electricity from renewable sources. Obligated entities' ESO will progressively rise at a rate of 0.5% per year, from 1% in 2023–2024 to 4% by 2029–2030.

(ii) PSP's legal status: As per the Ministry of Power notification dated Sept 19, 2025, under the Electricity Act, 2003:

   (a) The Energy Storage System including PSP may be developed, owned, leased, or operated by a generating company or a transmission licensee or a distribution licensee or a consumer or a system operator or an independent energy storage service provider.
   (b) The Energy Storage System owned and operated by and co-located with a generating station or a transmission licensee or a distribution licensee or a consumer, shall have the same legal status as that of the owner.

(iii) Waiver of ISTS Charges: For PSP, a 100% waiver of ISTS charges has been provided for Hydro PSP Projects for which the construction work has been awarded on or before 30th June 2028.

(iv) Guidelines for Procurement and Utilization of Battery Energy Storage Systems: The Ministry of Power, vide resolution dated 10.03.2022, has issued detailed guidelines for the procurement and utilization of BESS as part of generation, transmission, or distribution assets, or along with ancillary services. These guidelines, inter alia, provide standardization and uniformity in the procurement of BESS and a risk-sharing framework between various stakeholders involved in energy storage and storage capacity procurement, thereby encouraging competition and enhanced bankability of these projects.

(v) Rules for replacement of Diesel Generator (DG) sets with RE/Storage: The Electricity (Rights of Consumers) Amendment Rules, 2022, notified on 20th April 2022, mandates that consumers who are using Diesel Generator (DG) sets as essential backup power shall endeavor to shift to cleaner technology, such as renewable energy with battery storage, to encourage commercial and industrial consumers.

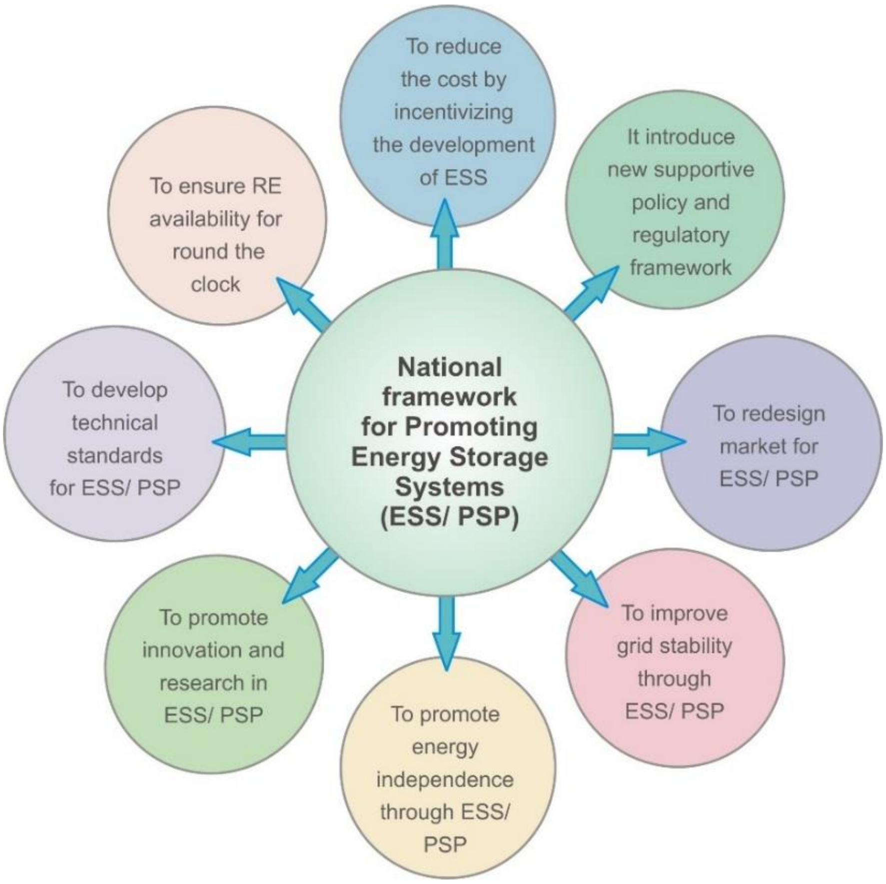

Figure 9.1: Objectives of National Framework for Promotion of ESS/ PSP

(vi) Guidelines for the development of PSP Projects: The Ministry of Power, Government of India, released guidelines in the form of "Guidelines to promote the development of Pumped Storage Projects" on April 10, 2023, in recognition of the necessity for the rapid and economical development of PSPs to improve the nation's energy security. The following criteria are included in the guidelines to help promote PSP growth in the nation:

1. Allotment of project sites: State governments can assign project sites to developers in one of three ways: (i) by nominating CPSUs and PSUs, (ii) by holding competitive bidding, or (iii) by using Tariff-Based Competitive Bidding (TBCB).
2. Timelines for beginning building work after project award: Within two years after the site allocation date, building must begin.

3. Self-identified off-stream PSP: Off-river PSP sites can be self-identified by the developer. No allotment by the State would be required.
4. No upfront premium for project allocation: No upfront premium is charged by the State for project allocation.
5. Market reforms for PSP: It has been suggested that electricity market reforms be carried out for the monetization of energy and ancillary services provided by PSPs.
    - Ancillary services that support grid stability are suitably monetized.
    - To provide appropriate pricing signals to peak and base-load generating plants.
    - PSPs shall be allowed to participate in all market segments of the power exchange.
    - During the monsoon period, 80% of the power generated from a PSP when no pumping energy is required would be offered to the home state at the rate of secondary energy fixed by the CERC. The remaining energy can be utilized to meet operation & maintenance costs and other expenses.
    - In the event of the capacity contracted not being fully utilized by the contracting agency, the developer would be free to transfer the usage of the capacity to other interested entities. The gains made shall be shared with the original beneficiary in the ratio of 50:50.

(vii) Financial Viability: PSPs are expected to be utilized to their full capacities. With high rates during peak hours, the PSP has the opportunity to optimize operations and earn suitable returns. Financial institutions like PFC, REC, and IREDA shall treat PSPs at par with other renewable energy projects while extending long-term loans of 20–25 years tenure. The debt-equity ratio of PSP projects can be up to 80:20, in consultation with the financial institutions.

(a) Taxes and Duties: States may exempt land to be acquired for off-river PSPs from payment toward stamp duty and registration fees. Government land, if available, may be provided at a concessional rate to developers on an annual lease rent basis. Electricity Duty (ED) and Cross Subsidy Surcharge (CSS) shall not be applicable on pumping power for the charging of PSPs.

(b) Exemption from Free Power Obligation: The PSPs would be kept out of the liability of free power.

Local Area Development Fund: PSPs, particularly off-river PSPs, have a minimal environmental impact and have no R&R (Resettlement and Rehabilitation) issues. Therefore, there will be no requirement for the creation of a Local Area Development Fund.

Utilization of exhausted mines to develop PSPs: Recommendations are made to utilize abandoned mines, including coal mines, to develop PSPs. Such sites may be identified in consultation with the Ministry of Coal, Ministry of Mines, and respective state governments.

Rationalization of Environmental Clearances for PSPs: It is recommended that PSPs constructed on existing reservoirs and on off-river sites may be treated as a separate category for the processing of clearances. MoEF&CC has provided relaxation in the clearance of PSP projects with conditions (CEA, 2023c).

Green Finance: PSPs may be supported through concessional climate finance. Sovereign Green Bonds, issued for mobilizing resources for green infrastructure as a part of the Government's overall market borrowings, may be deployed in the development of PSPs which utilize renewable energy for charging.

(i) Timely concurrence of Detailed Project Reports (DPRs): In June 2023, the CEA issued guidelines for the formulation of DPRs for PSPs. The timelines for the preparation of DPRs for PSPs located in Himalayan and non-Himalayan regions, depending upon geology, have been reduced. In addition, since no tariff/financial evaluation is required to be conducted by the CEA for PSP projects allotted through Tariff-Based Competitive Bidding or as part of an Integrated Renewable Energy Project or as captive plants, the CEA has reduced the timeline for concurrence of such projects.

(ii) Introduction of High-Price Day-Ahead Market (HP-DAM): A detailed framework for the HP-DAM segment in the existing Integrated DAM (I-DAM) was launched on 9 March 2023. Sellers with a high cost of generation would be allowed to participate. This will enable PSP developers to take suitable advantage of the price differential between peak and off-peak tariffs.

(iii) Harmonized Master List for Infrastructure: The Department of Economic Affairs has included ESS (which includes PSP) in the Harmonized Master List (HML) of infrastructure subsectors by the insertion of a new item in the category of ‘Energy’. This will ensure easier access to institutional credit and concessional funds, and reduce the developer’s cost of borrowing for projects related to these subsectors.

(iv) Budgetary support for enabling infrastructure for PSP: The Central Government is providing budgetary support for the construction of roads and bridges by providing up to ₹1.5 crore/MW for projects up to 200 MW and up to ₹1 crore/MW for projects above 200 MW.

(v) RE Must-Run Rules: The Electricity (Promotion of Generation of Electricity from Must-Run Power Plant) Rules, 2021 were notified on 22nd October 2021. These rules provide that a wind, solar, wind-solar hybrid, or hydropower plant, or a power plant from any other sources which has entered into an agreement to sell electricity to any person, shall be treated as a must-run power plant and should not be subjected to curtailment or regulation of generation or supply of electricity on account of merit order dispatch or any other commercial consideration. In the event of a curtailment of supply from a must-run power plant, compensation shall be payable. This incentivizes DISCOMs to purchase energy storage capacity so that excess solar power may be stored for use at night time when power demand is likely to peak.

(vi) Ancillary services from ESS (PSP) under CERC (Ancillary Services): The CERC (Ancillary Services) Regulations, 2022 were notified on 31st January 2022. These provide mechanisms for procurement, through administered as well as market-based mechanisms, deployment, and payment of ancillary services at the regional and national levels to maintain grid frequency within an allowable band and for relieving transmission congestion to support the reliable and stable operation of the grid. The regulations provide for the eligibility of PSPs to provide Secondary Reserve Ancillary Service (SRAS) and Tertiary Reserve Ancillary Service (TRAS) under certain conditions.

(vii) Inclusion of ESS (PSP) in Technical Standards for Connectivity to the Grid: The CEA has notified Technical Standards for Connectivity to the Grid Regulations, 2007 and its latest (Amendment) Regulations, 2019 on 6th February 2019, which provide the requirements to be complied with by ESS (PSP) to get connectivity to the grid at voltage levels of 33kV and above, enabling faster and smoother integration of PSPs with the grid.

(viii) Bidding guidelines for Round-the-Clock (RTC) RE Supply: Guidelines were notified in November 2020 for the Tariff-Based Competitive Bidding Process for the procurement of round-the-clock power from grid-connected renewable energy power projects. The firm power from PSPs can be utilized to balance renewable energy and provide Round-the-Clock (RTC) power to buyers/DISCOMs, thereby facilitating SLDCs in ensuring grid stability and security within their control jurisdiction.

Apart from the aforementioned policy measures to encourage PSP in the nation, the National Framework for Promoting ESS outlines other policy and regulatory measures that are either being considered now or may be considered in the future. These include financial incentives, Green Finance, guidelines for Resource Adequacy Plans, storage capacity with future renewable generations, technology-agnostic bidding guidelines for ESS procurement, regulatory measures, waiver of cess, taxes and duties, quality and standards, research and development, and more.

9.3 POLICY AND FRAMEWORKS BY STATE GOVERNMENTS FOR PROMOTION OF PSP

Some State Governments have developed policies and frameworks for PSP development in addition to the Central Government's promotion strategy and framework. The following paragraphs provide a brief description of these policies: (MoP, 2023; UKPSP, 2023; Burdett, 2024; CEA, 2024c; CEA, 2023c)

9.3.1 Government of Maharashtra PSP Promotion Policy - 2023[111]

Through public-private partnerships, the Maharashtra Government has put policies in place for the construction of PSPs, PSPs combined with Lift Irrigation Schemes (LIS), and PSP-Solar/Other Renewable Energy Hybrid Projects. To implement these policies, the PSPs are divided into three groups:

111 https://wrd.maharashtra.gov.in/Site/Upload/PDF/PSS%20POLICY%20dt%2020_12_23.pdf

- Category I: Refers to PSP sites that are owned or designated by the Maharashtra Government's Water Resources Department.
- Category II: Refers to PSP sites identified by the developer (Private or CPSE) in order to move water from west-flowing rivers to deficit basins.
- Category III: Refers to PSP cum LIS projects identified by the developer.

The policy lays out in detail the terms and conditions for co-located PSP-Solar and other RE hybrid projects, as well as the requirements for implementation, clearances, mandatory payments, the water allocation policy, generation, sale of energy, and regulatory measures. In addition, there are basic regulations such as taxes and duties, guidelines for preparing DPRs, and land acquisition.

Furthermore, the availability of Viability Gap Funding (VGF) for Category III PSP projects is an intriguing feature of Maharashtra's strategy. Although the precise amount of VGF has not yet been determined, the bidder's necessary VGF will be the primary selection criterion for these projects (in a transparent bidding process). The bidder with the lowest VGF is likely to win.

9.3.2 Uttrakhand Government - PSP Promotion Policy – 2024[113]

Incentives, including paying no more than 50% of intra-state transmission charges for five (5) years from the project CoD (Commissioning Date), are used to incentivize PSP developers. Off-stream PSPs will not be eligible for the Local Area Development Fund. The State Government is not allowed to obtain any free royalties. All project types must have approval for transfer or clearance on private property within eight weeks of application; water recycling between storage locations is exempt from water taxes.

Developers with existing operational or under-construction hydro projects in the state shall be given preference, and Single Window Clearance shall be made available. Clear-cut allotment conditions are provided, a time limit for executing projects is specified, and other policies for project development are clearly specified.

9.3.3 Government of Andhra Pradesh PSP Promotion Policy -2022[112]

The Andhra Pradesh Government developed an Integrated Clean Energy Policy for 2024. The goal is to get the state to invest in clean energy. With a potential to draw in investments of around INR 10,000,000 crores, the goal of this policy is to add more than 160 GW of renewable energy capacity. It is anticipated that this policy will establish Andhra Pradesh as a clean energy powerhouse and promote economic self-dependence. The state has planned to increase its capacity for the purchase of AP Discoms and the export of electricity to other states. It is anticipated that solar, wind, and PSP will contribute 78.50 GWp, 35 GW, and 22 GW of capacity, respectively. Significant capacity additions will also be made to other clean energy sources.

The eligibility criteria permit any developer setting up the PSPs either for captive/group captive use and/or for the sale of electricity to utilities or third parties within the state, or export to other

[112] https://nredcap.in/PDFs/Pages/GO_Ms_No_25_PSP_Policy.pdf

states, in accordance with the relevant Central/State regulations and/or Standard Bidding Guidelines (SBGs) issued and amended from time to time.

The policy framework encompasses clear norms for land facilitation, power evacuation and allotment, resource allocation, grid connectivity and power evacuation facilities, fees and charges, transmission & distribution/wheeling charges, cross-subsidy surcharges, and additional surcharges, etc. For PSP, the state government provides incentives for resource allocation, land allotment/facilitation, budgetary support, grid connectivity & power evacuation, waiver of stamp duty & registration fees, water allocation & charges, electricity duty, Cross Subsidy Surcharge (CSS), free royalty power, market reforms, etc[113].

9.3.4 Government of Odisha PSP Policy (July 2025) [114].

On July 28, 2025, the Power Department of the Odisha Government unveiled the Odisha Pumped Storage Projects (PSP) Policy. The Odisha Renewable Energy Policy 2022, which was issued in November 2022 by Resolution No. 11757_EN (dated 30th November 2022), is supplemented by this policy, which takes PSP advancements into account. This is done to make the state more conducive to the expansion of renewable energy initiatives. The involvement of the government, state, central PSUs, and the private sector may encourage and assist the growth of PSPs in the state. The Odisha PSP policy and the Odisha Renewable Energy Policy 2022 must be read together. The key components of the Odisha PSP policy are described in the paragraphs that follow:

The Objective of the Policy: The primary goals of the Odisha PSP Policy 2025 are to encourage the growth of pumped storage hydro projects in the state and to make it easier for renewable energy sources to be integrated into the grid. The distribution of state-identified PSPs and off-stream self-identified PSPs, their purchase by GRIDCO, DISCOMs, and SLDC, their usage in captive industry, their sale through Open Access, and any other uses that could be necessary for the state's RE development are all covered by this policy.

Allocation of Projects: According to the Odisha PSP policy, all state-identified projects must be shared through:

1. Joint ventures, Memorandums of Understanding (MoU), or nominations with CPSUs, SPSUs, or JVs following a comprehensive evaluation of their technical and financial capacity to finish the projects; and GRIDCO/DISCOMs' acquisition of power from such projects must be subject to the applicable regulations.
2. Using a composite Tariff-Based Competitive Bidding (TBCB) mechanism.
3. Using a competitive bidding process wherein bids will be invited based on revenue shared per unit of net energy sent out, or any other criterion determined by the Nodal Agency, subject to a threshold determined by it.

Allocation of Self-Identified Off-Stream Projects: Private developers may independently create off-stream PSPs in appropriate places if the Nodal Agency has not yet designated them

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[113] # Andhra Pradesh Integrated Clean Energy Policy 2024 (https://jmkresearch.com/wp-content/uploads/2024/10/AP-Policy.pdf

[114] https://investodisha.gov.in/download/odisha-psp-policy-2025.pdf

as state-identified projects. When allocating these to the developers, the state's interests can be considered.

Detailed methodology for application and allocation of PSP sites: The Nodal Agency will use a single window and a standard procedure to process all proposals, including captive PSP bids. If an industry and self-identified off-stream closed-loop PSP are developed as part of a composite industrial investment proposal, the composite application must be submitted to IPICOL's Industries Department, which will then forward the captive PSP-related proposal to the RE Nodal Agency for processing. Developers—including captive users—must register self-identified off-stream pumped storage projects with the Nodal Agency. A Pre-Feasibility Report (PFR) and a non-refundable one-time registration fee of INR 10,000/MW (up to INR 1 crore per project) must be submitted with the application.

Sale of Power: Unless the project is approved through TBCB, the OERC or CERC will determine the tariff for state-identified projects from which GRIDCO chooses to purchase the full amount of saleable power or capacity. At the time of allocation, GRIDCO would reveal if it intended to purchase all of the project's saleable power. Additionally, GRIDCO has the option to purchase all of the electricity from any project that the state has selected through the TBCB procedure. When PSPs function as conventional hydro, GRIDCO will receive 80% of the power generated during the monsoon season (June to September) at a secondary energy rate set by CERC or OERC. The developer will sell any remaining power during this time to pay O&M costs. In order to allow the plants to keep their CGP classification, the power that captive PSPs provide to GRIDCO will be regarded as presumptive use of CGPs.

The Incentives: The incentives applicable for PSP development include:

(i) PSPs are free from paying the electricity duty and cross-subsidy surcharge, regardless of where the input energy source is located.

(ii) There shall be no obligation for any free power or contribution toward the Local Area Development Fund (LADF).

(iii) No water cess shall be imposed on PSPs for the initial filling of water or for the yearly refilling of the necessary volume of water to be allotted by the Water Resources Department, as the water used in PSPs is for non-consumptive purposes. However, water charges shall be levied as applicable.

(iv) According to the Ministry of Power's Office Memorandum dated 28.09.2021, any updates thereto, or any other applicable Government of India plan, developers may be eligible to receive financial support from the Ministry of Power for the cost of enabling infrastructure.

Additionally, all incentives mentioned in the Odisha Renewable Energy Policy, 2022 (OREP-22) shall also be available.

Mode of Operation: All projects are to be created using the Build-Own-Operate-Transfer (BOOT) paradigm. The concession term will last 40 years under current laws and regulations, and it may be extended for a further 30 years with the State Government's consent. The projects will be fully transferred to the State Government at the conclusion of the concession period.

As long as the PSP maintains its CGP status, transfer clauses do not apply to PSP projects designed for captive consumption.

Progress of Development and Transfer: If the developer allotted a PSP site is shown to be squatting and does not make any significant progress on the land within two years of registration or two years after allocation, strict action will be taken. The State Government can prohibit a developer from working on any additional projects in the state, in addition to terminating their registration, project site assignment, and encashed Performance Guarantees. Ownership of the registered or assigned PSP site cannot be transferred until six months after the project is put into service, unless the State Government allows it in a particular situation.

Operational Guidelines: The Department of Energy of the Government of Odisha is required to develop regulations and complete operational guidelines for the execution of the Odisha PSP Policy within fifteen (15) days after the policy's introduction.

Further, any of the following policies may be reviewed, relaxed, altered, or interpreted by the Government of Odisha's Energy Department as needed. The Department of Energy will offer explanations and interpretations if any section of this policy becomes challenging to execute.

Further, a number of states, including Gujarat, Madhya Pradesh, Tamil Nadu, Kerala, and Karnataka, are also drafting their own PSP policies and guidelines.

9.4 PSP'S PRICING MECHANISM IN INDIA

9.4.1 Development of Pumped Storage Hydropower CERC Tariff Regulations

The Central Electricity Regulatory Commission (CERC) established the first Tariff Regulation for PSP in 2009–2014 as Terms and Conditions for Tariff Regulation. PSP tariff regulations were not included in the original Terms and Conditions for Tariff Regulation (2009–2014); nonetheless, they were added as a third amendment to the regulations. Table 9.1 provides a concise overview of the development of CERC Tariff Regulations for PSP starting in 2009.

Table 9.1: Development of Tariff Regulations for Pumped Storage Hydropower in India

Particulars	2009 - 14	2014 -19	2019 - 24	2024 - 29
Capacity charge for PSP	Not specified in the original Term and Conditions for Tariff Regulation. Later, included in Third Amendment in 2013. The Capacity Charge for the Month = AEC x NDM/NDY in Rupee, if actual	The Capacity Charge for the Month = AEC x NDM/NDY in Rupee, if actual Generation during the month is more than or equal to 75% of the pumping energy consumed by the station during the month = (AFC x NDM/NDY) x (Actual generation	The Capacity Charge for the Month = (AFC x NDM / NDY) (In Rupees), if actual Generation during the month is >= 75 % of the Pumping Energy consumed by the station during the month and {(AFC x NDM / NDY) x (Actual	The Capacity Charge for the Month = (AFC x NDM / NDY) (In Rupees), if actual Generation during the month is ≧ 75 % of the Pumping Energy consumed by the station during the month and {(AFC x NDM / NDY) x

Particulars	2009 - 14	2014 -19	2019 - 24	2024 - 29
	Generation during the month is more than or equal to 75% of the pumping energy consumed by the station during the month = (AFC x NDM/NDY) x (Actual generation) during the month during Peak hoursh /75% of the energy consumed by the station during the month in Rs If actual generation during the month is less than 75% of the pumping energy consumed by the station during the month.	during the month during peak hrs/75% of the energy consumed by the station during the month in Rupees If actual generation during the month is less than 75% of the pumping energy consumed by the station during the month.	Generation during the month during peak hours/ 75% of the Pumping Energy consumed by the station during the month) (in Rupees)}, if actual Generation during the month is < 75 % of the Pumping Energy consumed by the station during the month	(Actual Generation during the month during peak hours/ 75% of the Pumping Energy consumed by the station during the month) (in Rupees)}, if actual Generation during the month is < 75 % of the Pumping Energy consumed by the station during the month.
Energy Charge for PSP	Introduced in Terms and conditions for Tariff Regulation in Third Ammendment 2013. Energy charge for the Month = 20 Paise/kWh of total energy scheduled in excess of design energy plus 75% of the energy consumed in pumping of water from lower reservoir to upper reservoir excluding free energy, if any.	Energy charge for the Month = 20 Paise/kWh of total energy scheduled in excess of design energy plus 75% of the energy consumed in pumping of water from lower reservoir to upper reservoir excluding free energy, if any.	Energy charge shall be payable by every beneficiary for the total energy scheduled to be supplied to the beneficiary in excess of the design energy plus 75% of the energy utilized in pumping the water from the lower elevation reservoir to the higher elevation reservoir, at a flat rate equal to the average energy charge rate of 20 paise per kWh, excluding free energy, if any, during the calendar month, on ex power plant basis.	The energy charge shall be payable by every beneficiary for the total energy scheduled to be supplied to the beneficiary in excess of the design energy plus 75% of the energy utilized in pumping the water from the lower elevation reservoir to the higher elevation reservoir, at a flat rate equal to the average energy charge rate of 20 paise per kWh, if any, during the calendar month, on ex power plant basis.

Particulars	2009 - 14	2014 -19	2019 - 24	2024 - 29
				ROE for new PSP project achieving COD on or after 01.04.2024 shall be computed at the base rate of 17.00% for pumped storage hydro generating stations.
AFC = Annual fixed cost specified for the year, in Rupees; NDM = Number of days in the month; NDY = Number of days in the year				

Source;
CERC (2009) https://cercind.gov.in/Regulations/Terms-and-Conditions-of-Tariff-Regulations_2009-2014.pdf
CERC (2014) https://cercind.gov.in/2016/regulation/1.pdf
CERC (2019) https://www.cercind.gov.in/2019/regulation/Tariff%20Regulations-2019.pdf
CERC (2024) https://cercind.gov.in/regulations/notification-2024.pdf

9.4.2 Pricing mechanism

Electricity generated by PSPs in India is subject to a tariff based on a two-part pricing structure consisting of "fixed cost" and "variable cost," as per the Central Electricity Regulatory Commission (Terms and Conditions of Tariff) Regulations, 2024[115]. The variable cost, also known as the energy charge, is used to recover the costs incurred during plant operation (O&M), whereas the fixed cost, also known as the capacity charge, covers the capital cost (CAPEX) that must be recovered annually for the cost of the plant, including equipment, administrative costs, and labor costs, among other things (CERC, 2024; REPA-EF HyFi, 2024; CSTEP, 2021).

The monthly energy charge that must be paid to the generating company is equal to: 0.20 × {Scheduled energy (ex-bus) for the month in kWh – Design Energy for the month (DEm) + 75% of the energy used to pump water} / 100.

where **DEm** = Design energy, expressed in MWh, for the hydro producing facility for the given month.

Fixed Cost and Capacity Fee: In accordance with CERC (2024) regulations, a PSP generating station's fixed cost must be calculated annually, and its capacity charge is recovered monthly. This capacity charge is paid by the beneficiaries in accordance with their individual allocation, which in this case is the saleable capacity of the PSP plant or generating station. The most recent projected PSP generating station completion cost must be used to calculate the annual fixed cost for the period between the first unit of the PSP generating plant going into commercial operation and the date of the generating station's commercial operation. Therefore, the payment for capacity charges is calculated for such a time.

115 https://www.cercind.gov.in/regulations/notification-2024.pdf

Return on Equity: According to Regulation 18 of CERC (2024), the return on equity (RoE) for the computation of the annual fixed cost is computed in rupee terms on the equity base. The RoE for an existing PSP generating project is calculated at 16.5% of the base rate, whereas the RoE for a new PSP generating station with a COD on or after April 1, 2024, is calculated at 17% of the base rate. However, the return on equity is calculated using the base rate of the State Bank of India's one-year marginal cost of lending rate (MCLR) plus 350 basis points as of April 1st of that year, up to a maximum of 14%, in cases of additional capitalization beyond the original scope or due to a change in law or force majeure. Also covered by the PSP's working capital are:

1. Receivables equal to 45 days of annual fixed costs.
2. Maintenance spares at 15% of O&M costs, including security costs.
3. O&M, including security costs, for a month (CERC, 2024).

Until the recent past, PSPs were treated similarly to conventional hydropower plants, and their purpose was simply believed to be as a generating plant; thus, the pricing mechanism followed was designed to recover costs through the sale of power to beneficiaries at a specified tariff structure. However, PSPs were not recognized for their genuine role as both a generating unit and a consumer unit. A PSP plant functions as a generating unit during periods of peak load, helping to balance the grid by fulfilling load requirements. During off-peak periods, it functions as a consumer unit, using extra grid electricity to pump water into the upper reservoir for storage. The pricing method for these two operation modes must differ since a PSP functions as a generating unit during peak load periods and as a consumer during off-peak load periods. This is necessary to ensure that PSPs receive fair compensation for the services they render to the power system.

For instance, for the Tehri PHES plant during 2019–2020, there were 21 and 53 no-profit days, respectively. The average peak price (INR per kWh) during 2019 and 2020 was ₹7.5 and ₹5.3, respectively. Similarly, the off-peak price (INR per kWh) during 2019 and 2020 was ₹2.25 and ₹1.95, respectively. The ratio of average peak price to off-peak price required to generate profit during 2019 and 2020 was 1.35 and 1.33, respectively. The total profit during 2019 was INR 157 crores (market price), whereas during 2020 it reduced to INR 70 crores (market price). Thus, the fixed cost recovery during 2019 and 2020 was 16% and 7%, respectively. It is realized that if a PHES plant operating in the market has to provide grid flexibility, there is a reduction in the overall profit earned by the plant (CSTEP, 2021; REPA-EF HyFi, 2024)[116].

Additionally, the CERC (Ancillary Services) Regulations, 2022 were notified on January 31, 2022, as part of the national framework for promoting energy storage. These regulations were designed to develop a mechanism for procurement, deployment, and payment of ancillary services at the regional and national level in order to maintain grid frequency within the permitted band and to relieve transmission congestion (MoP, 2023). Furthermore, the regulations aim to maintain grid frequency close to 50 Hz and ensure the safety and security of the grid.

116 CSTEP. (2021). Pricing Mechanism of Pumped-Hydro Storage in India. (CSTEP-PB-2021-06). (https://cstep.in/drupal/sites/default/files/2021-06/Pumped-hydro%20policy%20brief_30June21.pdf)

9.4.3 Provision of Type of Ancillary Services in CERC Regulation

The following categories of ancillary services are taken into consideration in the CERC (Ancillary Services) Regulations:

(a) Primary Reserve Ancillary Service (PRAS)
(b) Secondary Reserve Ancillary Service (SRAS)
(c) Tertiary Reserve Ancillary Service (TRAS) and
(d) Such other ancillary services, including but not limited to Voltage Control Ancillary Services and Black Start Ancillary Services, as specified in the Grid Code.

The entire method of procurement, deployment, and payment of SRAS and TRAS is outlined in the CERC (Ancillary Services) Regulations. The regulations provide the means for the eligibility of PSPs to supply Secondary Reserve Ancillary Service (SRAS) and Tertiary Reserve Ancillary Service (TRAS) under specified conditions. As a result, it gives PSP service providers another source of income and encourages investment in the PSP industry.

The regulation states that an SRAS Provider (PSP in the present case) shall be paid from the Deviation and Ancillary Service Pool Account at the rate of their energy charge or compensation charge, as declared by the SRAS Provider, for the SRAS-Up MW quantum dispatched for every 15-minute time block. Conversely, the SRAS Provider shall pay back to the Deviation and Ancillary Service Pool Account at the same rate for the SRAS-Down MW quantum dispatched. The SRAS Provider shall also be eligible for incentives based on performance as per the specifications given in the regulation.

In order to be eligible to participate as a TRAS Provider, a generating station, an entity with an energy storage resource (PSP Plant), or an entity that can provide demand response must:

1. Be able to vary its active power output, drawl, or consumption upon receiving dispatch instructions from the Nodal Agency.
2. Be able to provide TRAS within 15 minutes and maintain the service for at least the next 60 minutes.

TRAS will be activated and deployed by the Nodal Agency in response to the following events:

- (a) If the secondary reserve has been deployed continuously in one direction for fifteen (15) minutes for more than 100 MW.
- (b) Other events as defined by the Grid Code.

For the amount of TRAS-Up cleared in the Day Ahead AS Market (DAM) or the Real Time AS Market (RTM) but not directed to be dispatched, the provider will be paid commitment charges at the rate of 10% of the MCP Energy-Up-AS-DAM or MCP-Energy-Up-AS-RTM, up to a maximum of 20 paise/kWh (CERC, 2022).

Pricing Discovery for TRAS-Up and TRAS-Down: The TRAS-Up price, which is subject to market splitting in the event of congestion, is established using the Uniform Market Clearing

Price approach. According to Regulation 16, the highest Energy-Up bid that satisfies the requirement for TRAS-Up will be the Market Clearing Price (MCP).

In February 2023, NLDC developed a draft detailed procedure for Tertiary Reserve Ancillary Service (TRAS). The purpose of the procedure was to establish the roles and methodology that the Nodal Agency (NLDC), RLDCs, SLDCs, RPCs, and Power Exchanges must adhere to for the operational aspects of TRAS procurement, deployment, and payment (NLDC, 2023).

According to the discussion above, ancillary services are becoming increasingly important to the Indian power grid. Additionally, SRAS and TRAS services point to a shift toward market-based ancillary service procurement, which can give PSPs access to other revenue streams.

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CHAPTER 10: CHALLENGES FOR PSP DEVELOPMENT IN INDIA

10.1 OVERVIEW

The Indian Government has taken a number of actions in recent years to support the growth of PSP in India. The Ministry of Power, Government of India, released guidelines in April 2023 that offer a number of incentives for PSP growth (CEA, 2023c)[117]. In August 2023, a National Framework was put into place to promote energy storage systems, including PSP (MoP, 2023). This is helping to improve energy storage and provides a defined structure and guidelines for the country's PSP development.

The Ministry of Power has proposed a number of market reforms, and relevant commissions have been requested to see to it that these are implemented.

10.2 MAJOR CHALLENGES FOR PSP DEVELOPMENT IN INDIA

Major challenges that are being encountered for the development of PSP are as follows:

10.2.1 Policy and clearance process

(i) **Delays in Environmental and Forest Clearances:** Prior experience has demonstrated that delays in environmental and forest clearances have posed a significant challenge for the majority of river valley projects, including PSPs. However, off-river sites and existing reservoirs are being considered as a distinct category for clearance processing because of the rationalization of environmental clearances for PSPs under specific criteria. Off-river PSP projects only use one season's worth of data for their Environmental Impact Assessment (EIA), whereas in-stream projects need a year's long data to enable early clearance. However, comparable procedures and inquiries are frequently used in actual practice at the state and clearance levels.

(ii) **Water Availability and Conflicting Demands:** In India, where water is scarce, allocating water resources to PSPs is difficult due to conflicting demands for industrial, drinking, and irrigation water. Due to evaporation and seepage losses, PSPs may have to pay water user fees for initial filling as well as recouping the losses, and other uses may take precedence over PSPs when allocating water. PSP operations may also be impacted by seasonal changes in water availability, especially as a result of the impact of climate change.

(iii) **Statutory Bodies:** The view of the regulatory organizations that handle clearances and vetting is based only on recent large hydro projects that have or are expected to have long durations, high costs, and challenging marketing. They do not have access to enough successful international models, which causes delays at every stage.

[117] https://powermin.gov.in/sites/default/files/Guidelines_to_Promote_Development_of_Pump_Storage_Projects.pdf (CEA,

10.2.2 Land acquisition and related matter

(i) **Land Acquisition and Rehabilitation and Resettlement (R&R):** Land acquisition and R&R issues in several instances led to local unrest and law-and-order issues. Land acquisition may be delayed by India's complicated land ownership patterns and the need for comparatively vast land holdings for upper and lower reservoirs, which may include agricultural or forested areas. Due to the several issues-including not just land ownership but also biodiversity and wildlife-in-stream schemes where new reservoirs are developed result in significant delays. Although these problems might be site-specific, the community and local government may need to step in to secure a cooperative resolution in order to support the project's timely progress.

(ii) **Rugged Terrain and Adverse Geological Conditions:** Potential PSP sites are frequently found in regions with harsh topography and unfavorable geological characteristics, especially in the Western Ghats or Himalayan states. These locations frequently present challenges during construction due to unexpected geology. This frequently raises the cost and may cause delays in construction. Adequate studies for current and predicted adverse conditions can address a large number of such issues.

10.2.3 Finance

(i) **High Capital Investments:** Depending on the PSP's capacity and type (off-river closed-loop, or open-loop or on-river open-loop), the capital investment varies significantly. PSP capital costs may have lengthy payback periods, which makes project financing difficult. Complex civil engineering projects, specialized electromechanical equipment, and frequently isolated sites are the causes of this high cost. According to Indian experience, the majority of hydropower projects, including PSPs, have experienced major delays of several years, resulting in considerable cost and schedule overruns.

(ii) **Financial Closure of PSP Projects:** Since the majority of PSP projects have been constructed by Government organizations and because PSPs have a lengthy gestation time, private financing is difficult for them. Key barriers include the cost structure and capital intensity, delays and cost overruns in construction, the absence of an economic model that provides the actual value of PSPs, insufficient motivation for financial institutions to assist the industry, and societal and environmental issues.

10.2.4 Technological Challenges

(i) **Competition from Other Technologies:** PSP's main rivals are battery energy storage systems (BESS). Developers and policymakers are concerned about PSP's ability to compete with BESS given its declining pricing. This concern is unwarranted, even though, variety of energy storage technologies are needed, given that electricity is a public utility with significant effects on energy security and independence. Furthermore, 70–80% of PSP components are generated domestically, and unlike Li-ion-based BESS, it does not rely on imports for essential materials. These factors suggest that PSP development needs to be approached aggressively in order to fulfill RE targets without endangering grid reliability.

(ii) **Capacity to Execute:** Technical capacity—including the number of experts and consultants needed for any PSP project, surveys and investigations, geological and geotechnical investigations, the suitability of construction materials, the procedures for tendering, and the availability of qualified civil contractors, equipment suppliers, and power evacuation—is currently insufficient.

10.2.5 Capacity Building

(i) **Public Awareness and Acceptance:** Public awareness, particularly among policymakers and the general public, is lacking regarding the importance of providing a high-quality, round-the-clock power supply to all citizens of the nation, where PSP can readily be advantageous. Environmental issues are a common source of worry for local people, especially when it comes to water bodies and forest regions. The general public does not fully comprehend the advantages of PSPs in promoting grid stability and the incorporation of renewable energy.

10.2.6 Private Sector Involvement

Private sector in PSP development: The private sector is very much interested in developing PSP though it has not been heavily involved in the development of hydropower and now sees it as an essential asset for growing solar and wind projects. The PSP, like hydro, has deep settings, tunnels, and reservoirs. It also requires the highest level of safety when using the water that is used for irrigation and drinking. Any lack of safety could have a significant negative impact on the public opinion, government approval, and both domestic and foreign investment. Only thorough investigations and an integrated framework that addresses every facet of extreme events can guarantee such safety, which calls for patience and a longer time frame than solar and wind installation.

10.2.7 De -risking PSP development

To assure the techno-economic feasibility of the project, effective de-risking techniques to reduce the risks related to PSP project development are not readily available[118].

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[118] IHA, Enabling new pumped storage hydropower A guidance note for key decision makers to de-risk pumped storage investments, p40, https://indd.adobe.com/view/0d14c1da-75a4-4c48-b9cc-1896f279605c

CHAPTER 11: RECOMMENDATIONS

In order to mitigate the challenges being faced in the development of PSP in India, following recommendations are proposed:

11.1 POLICY

(i) **PSP Site Allocation:** States are being encouraged to announce PSP site allocations through their policies by specifying timetables and locations via a transparent procedure involving DISCOMs, generating companies, traders, and regulators. The Ministry of Power and CEA have made guidelines available to the states for developing policies and working out energy storage requirements. Due to their dynamic nature, storage requirements—whether single or cumulative—need to be examined and revised every two years or sooner.

(ii) **Priority to Off-River PSP Development:** Prioritizing off-river PSP development will reduce the time required for clearances and result in lower investments and fewer challenges.

(iii) **Development of Infrastructure Specific to Energy Storage Systems:** Appropriate transmission capacity is necessary due to the scattered locations of RE facilities and potential sites for energy storage systems. For the efficient construction and use of geographically scattered energy storage systems, the recently proposed Green Energy Corridor should be appropriately utilized.

(iv) **Processes for Integrated Approval:** Despite being in charge of single-point clearance, the CEA depends on four additional organizations run by other ministries, in addition to the MoEF&CC, for environmental and forest clearances. Only after receiving the necessary consent, the state government agency may choose to designate a location for execution. Since PSP is an energy security measure, it may be designated as a "National Project" to receive particular attention and priority consideration from all agencies.

(v) **Indigenous Technology:** As PSP technology is almost indigenous in comparison to other storage technologies like batteries, the government must support it to prevent reliance on imports.

(vi) **Cooperative Development and the UMPP Model:** Proactive assistance from the Central Government could greatly accelerate the execution of PSP projects, though more thrust is required at the state level to reduce establishment delays. Furthermore, for maximum utilization, reduced development costs, and a lower burden on each beneficiary through cost-sharing, several states, central bodies, and/or DISCOMs may work together to build PSPs.

At the national or state level, PSPs might be developed by implementing a model similar to the Ultra Mega Power Project (UMPP) model. Accordingly, PSPs may be created via a competitive bidding approach to choose the most effective developer by expediting statutory clearances, land acquisition, and project implementation. In order to plan projects, acquire land, secure permissions, and manage competitive bidding, a Special

Purpose Vehicle (SPV) may be established within the Ministry of Power as a subsidiary of a CPSU.

(vii) **Long-Duration Procurement:** Since pumped storage is a long-term and durable energy storage alternative for DISCOMs and major energy customers, the Government of India, state governments, and electricity regulators must acknowledge these demands and should create a separate development and procurement plan for it.

11.2 INSTITUTIONAL

(i) **Identification of New PSP Sites and Technologies:** Efforts must be undertaken to locate and construct off-stream PSP sites on existing reservoirs. Additionally, novel technologies—such as solid gravity storage, the use of the sea, abandoned mines, and small-scale PSP—should be developed on a pilot basis. Despite the abundance of large PSP sites in the country, pilot-scale projects based on innovative technology should be encouraged to determine the level of technological preparedness for commercial adoption in light of global trends and to conserve civil construction resources.

(ii) **Improved Utilization of New and Upcoming PSPs:** Procedures for the most effective usage of PSP plants should be developed by national and state load dispatch centers (NLDCs/SLDCs). In the past, there have been cases where some PSPs were simultaneously running in generating and pumping modes. If grid conditions allow, such scenarios should be prevented to maximize system efficiency.

(iii) **Robust Project Management:** Use effective project management techniques—such as thorough planning, frequent progress reports, and contingency plans—to help reduce delays and expenses. In order to effectively manage resources, monitor progress, and remove obstacles, widely used construction project management software should be utilized in conjunction with appropriate capacity building.

(iv) **Hybrid PSP Projects and Grid Services:** PSPs can be utilized to provide stable electricity and lessen the unpredictability of renewable energy sources, but these services are often not directly compensated. Furthermore, as India rapidly moves toward a high-renewable energy-based power grid, the system should compensate for the inertia support, short-circuit strength, and black-start assistance that PSPs offer.

11.3 REGULATORY

(i) **Quantifying the Value of Pumped Storage:** With inertia, short-circuit current, high reactive power support capabilities, and decades of operator experience, PSP is a long-lasting, long-duration, and high-power capacity energy storage technology. The value of PSP for Atmanirbhar Bharat and other grid support services—which inverter-based resources cannot deliver, or supply only at significantly higher costs—must be assessed before a workable business plan for PSP can be created in India. To establish the monetary worth of reliability and further support investment for a high-RE future, the Value of Lost Load (VoLL) should also be evaluated. The cost-benefit ratio of PSPs will become more apparent once these benefits are monetized, facilitating the creation of market-based or government-based incentives.

(ii) **Market-Based PSP Capacity Procurement:** The establishment of a capacity market in India has been the subject of recent discussions. These long-term signals should indicate the location and quantity of PSP required, which will then be paid to develop the plant after clearing capacity auctions. The risk of developing PSP projects can be decreased and their financial appeal raised through such a market-based price discovery method.

(iii) **Notification of Regulations:** Based on the CEA's Resource Adequacy Report, the SERCs may request that state DISCOMs (both private and public) to include energy storage in their electricity portfolios, particularly for extended periods to mitigate "solar and wind droughts." Nonetheless, federal and state regulators will need to enforce these obligation targets alongside appropriate systems for compliance, non-compliance penalties, and performance evaluation. To advocate for sustainable energy storage while balancing consumer interests and financial viability, the Forum of Regulators (FoR) may also consider researching and creating model regulations for all state regulators.

(iv) **Cross-Border PSP Development:** In view of the large hydro and PSP potential available in Bhutan and Nepal, cross-border trading needs to be encouraged to optimize regional energy resources.

(v) **PSP Ancillary Services:** Energy storage facilities are permitted to offer secondary and tertiary reserve ancillary services under the CERC Ancillary Services Regulations (2022). To strengthen their financial viability, PSPs should be offered further incentives for rapid "up" and "down" power regulation.

(vi) **Supply Chain and Manufacturing Drivers:** At present, the ratio of imports varies greatly, and not all energy storage technologies are entirely made in India. Despite having the highest domestic content among storage options, PSP still relies on imports for some components. Newer technologies, like hydrogen and battery storage, have a much greater dependence on imports. Efforts must be made to reduce the import of critical components. For instance, if a large pipeline of PSPs is scheduled for construction, it will become cost-effective to manufacture these components in India, paving the way for future exports.

(vii) **Land Acquisition:** State governments may choose to acquire the land directly and allot it to PSP developers to streamline project timelines.

11.4 CAPACITY BUILDING

(i) **Capacity Building:** For PSP technologies to be deployed on time, increased technical assistance, education, and training are required for the creation of new codes, standards, and regulations. Because geotechnical testing and investigations are time-intensive, capacity augmentation is crucial. Since the Himalayan nations of Bhutan and Nepal are integral to India's hydropower potential utilization, regional cooperation and knowledge exchange should be promoted.

(ii) **Improved PSP Modeling and Simulations:** PSP models should be developed for a range of technologies and for analyses to be carried out across various timelines. These models are essential for accurate power system planning and operation, ensuring that simulated behavior closely resembles the actual performance observed in the field.

(iii) **Early Stakeholder Engagement:** Involving local communities and landowners early in the project planning stage fosters trust, reduces resistance, and can significantly cut down on delays.

11.5 FINANCING

(i) **Secure Funding:** Early and stable finance agreements can prevent delays brought on by financial uncertainty. Flexible financing solutions, such as public-private partnerships (PPPs) and green bonds, can be utilized to diversify funding sources and lower financial risks. For energy storage projects, options such as a higher return on equity and viability gap funding should be taken into consideration. Such alluring returns will entice lenders to finance storage projects. Additionally, the project budget should include contingency funds to address unforeseen cost increases arising from site-specific and market variables.

(ii) **Markets and revenues:** When conducting economic comparisons between various storage technologies, policymakers and project developers ought to adopt a uniform, technology-neutral methodology and take into account the advantages of assets across their whole lifecycle.

(iii) **Project development:** Early in the development phase, assign full delivery teams comprising the owner, operator, designer, constructor, OEM, and others.

(iv) **Allocation of risk:** Procurement and contract management should ensure fair, transparent, and economically most advantageous conditions for the project.

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REFERENCES

Aubert, S., P. Steimer, S. Linder, and C. Hillberg. 2014. "Variable Speed Pumped Storage with Converter-Fed Synchronous Machines (CFSM) — A High Value in Grids with Large Penetration of Wind and Solar Generation." Proceedings of HYDRO 2014, Lake Como, Italy, October 13–15, 2014.

Balducci, P., R. Fan, K. Mongird, J. Alam, A. Somani, J. Steenkamp, D. Wu, D. Bhatnagar, and Y. Yuan. 2018. Shell Energy North America's Hydro Battery System, Final Market Assessment Report, PNNL-27620, Pacific Northwest National Laboratory (PNNL), Richland, WA

Blakers, A., Stocks, M., Lu, B., Cheng, C. 2021. A review of pumped hydro energy storage, Prog. Energy 3, 022003.

Barbour, E., Wilson, I.A.G, Radcliffe, J., Ding, Y., Li, Y. 2016. A review of pumped hydro energy storage development in significant international electricity markets. Renewable and Sustainable Energy Reviews. 61, 421 - 432

Blakers, A and Stocks, M. (2017).90-100% renewable electricity for the South West Interconnected System of Western. Australia, Australian National University, https://www.sciencedirect.com/science/article/pii/S0360544217300774

Burdett, M. (2024). Asia-Pacific leads pumped-storage renaissance. Hydropower & Dams Issue One, 2024: 72 - 77.

Carr, A. (2017), "First-ever hydro and solar power hybrid plant opens in Portugal", The Weather Channel, 10 July, https://weather.com/science/ environment/news/portugal-alto-rabagao-damsolar-hydro-power-panels-energy.

CBIP, Pumped Storage Schemes in India, Publication No. 265, November 1997; Central Board of Irrigation and Power

CEA (Central Electricity Authority) (2024b) Pumped storage potential in the country (Status as on 30.4.2024) https://cea.nic.in/pumped-storage-plants/?lang=en , accessed on 13.9.2024

CEA (Central Electricity Authority) (2024c). Pumped storage potential in country (India) (As on Sept..2024) (https://cea.nic.in/pumped-storage-plants/?lang=en). accessed on 10.9.2024

CEA (Central Electricity Authority) (2024e). Capacity addition plan of PSPs till 2031-32 (As on Sept..2024) (https://cea.nic.in/pumped-storage-plants/?lang=en). accessed on 10.9.2024

CEA (Central Electricity Authority) (2024f). Pumped Storage Projects granted ToR by MoEF&CC (status as on 30.5.2024) (https://cea.nic.in/pumped-storage-plants/?lang=en)

CEA (2024g) Vision and Mission of Central Electricity Authority https://cea.nic.in/vision-mission-of-cea/?lang=en#:~:text=Central%20Electricity%20Authority%20seeks%20to,to%20carry%20out%20project%20monitoring%2C

CEA (2023a) REASSESSMENT OF 0N-RIVER PUMPED STORAGE HYDROELECTRIC POTENTIAL IN INDIA, Central Electricity Authority, Ministry of Power. Pp. 528. (https://cea.nic.in/wp-content/uploads/hp___i/2023/08/Pumped_Storage_On_River_Final_compressed.pdf) (Ref. 137)

CEA (2023c) Guidelines on Pumped Storaqe Proiects (10 April 2023)

(https://powermin.gov.in/sites/default/files/Guidelines_to_Promote_Development_of_Pump_Storage_Projects.pdf)

CEA (2025d) https://cea.nic.in/wp-content/uploads/hpi/2025/01/Status_of_Pumped_Storage_Development_in_India_3.pdf

CERC (Central Electricity Regulatory Commission) 2024, Notification no. L-1/268/2022/CERC Dated 15th March, 2024 (https://www.cercind.gov.in/regulations/notification-2024.pdf)

CERC (Central Electricity Regulatory Commission) (2024) (FUNCTIONS(MANDATE) of Central Electricity Regulatory Commission (CERC) (https://www.cercind.gov.in/Function.html)

CERC (Central Electricity Regulatory Commission) (2022) Central Electricity Regulatory Commission (Ancillary Services) Regulations, 2022. (31st January 2022) https://cercind.gov.in/Regulations/Ancillary-Service-Regulations-2022.pdf

CERC (Central Electricity Regulatory Commission) (2019) Central Electricity Regulatory Commission (Terms and Conditions of Tariff) Regulations, 2019 (https://www.cercind.gov.in/2019/regulation/Tariff%20Regulations-2019.pdf)

Chen, Y., A. Odukomaiya, S. Kassaee, P. O'Connor, A.M. Momen, X. Liu, and B.T. Smith. 2019. "Preliminary analysis of market potential for a hydropneumatics ground-level integrated diverse energy storage system," Applied Energy 242:1237–1247. Available at: https://doi.org/10.1016/j.apenergy.2019.03.076..

China Energy Portal, 2021. Medium and long-term development plan for pumped hydro energy storage (2021-2035) https://chinaenergyportal.org/en/medium-and-long-term-development-plan-for-pumped-hydro-storage-2021-2035/

Colas, E., Klopries, E.M., , Tian, D., Kroll, M., Selzner, M., Bruecker, C., Khaledi, K., Kukla, P., Preuße, A., Sabarny, C., Schüttrumpf, H., Amann, F. (2023) Overview of converting abandoned coal mines to underground pumped storage systems: Focus on the underground reservoir. Journal ofr Energy Storage. 73: 109153

CSTEP (Center for Study of Science, Technology and Policy). (2021). Pricing Mechanism of Pumped-Hydro Storage in India. (CSTEP-PB-2021-06). https://cstep.in/drupal/sites/default/files/2021-06/Pumped-hydro%20policy%20brief_30June21.pdf

Das., B (2023) Unlocking power of pumped storage hydropower: A sustainable energy solution, Renewable Energy. Down to Earth (https://www.downtoearth.org.in/renewable-energy/unlocking-power-of-pumped-storage-hydropower-a-sustainable-energy-solution-91959)

Deane, J.P.; Gallachóir B, Ó.; McKeogh, E.J. (2010). Techno-economic review of existing and new pumped hydro energy storage plant. Renew. Sustain. Energy Rev. 14, 1293–1302.

DOEb (U.S. Department of Energy). 2016. Hydropower Vision: A New Chapter for America's First Renewable Electricity Source. Available at: https://www.energy.gov/sites/prod/files/2016/10/f33/Hydropower-Vision-10262016_0.pdf.

EDP (Energias de Portugal) (2017), "Pioneering floating photovoltaic solar project surpasses expectations", EDP news, 4 December, https://portugal.edp.com/en/news/2017/12/04/pioneering-floating-photovoltaic-solar-projectsurpasses-expectations. Energy Magazine (2018)

EMBER (2024) Global Electricity Review (2024) Pp. 199

(https://ember-climate.org/app/uploads/2024/05/Report-Global-Electricity-Review-2024.pdf)
Energy Magazine (2018), "World's first integrated solar pumped hydro project", 19 February, www.energymagazine.com.au/ worlds-first-integrated-solar-pumped-hydroproject.
FERC (Federal Energy Regulatory Commission). 2019. Final Environmental Assessment for Hydropower License: Hydro Battery Pearl Hill Pumped Storage Project, FERC Project No. 14795-002, Washington, DC. Available at: https://www.ferc.gov/sites/default/files/2020-06/P14795-EA.pdf.
GESDB (Global Earth System Data Bank) (2020) Global data on Pumped Storage Hydropower projects, available from Sandia National Laboratories Corporation. https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/11/ GES DB_Projects_11_17_2020.xlsx
Hahn, H., Hau, D., Dick, C., & Puchta, M. (2017). Techno-economic assessment of a subsea energy storage technology for power balancing services. Energy, 133, 121–127. doi:10.1016/j.energy.2017.05.116https://media.istockphoto.com/id/153065178/photo/uranium-mine.jpg?s=1024x1024&w=is&k=20&c=QutY9icYD4ZeD3IadBEDI41f2T1ab8kchjDCa3UMj-0=
Hino, T., & Lejeune, A. (2012). Pumped Storage Hydropower Developments. Comprehensive Renewable Energy 6:405–434. doi:10.1016/b978-0-08-087872-0.00616-8
https://en.powerchina.cn/2022-09/29/c_817026.htm
https://www.ge.com/renewableenergy/stories/hohhot-flexible-storage
https://en.powerchina.cn/2022-09/29/c_817026.htm
https://www.power-technology.com/data-insights/power-plant-profile-changlongshan-china/
https://en.powerchina.cn/2022-09/29/c_817026.htm
https://www.gevernova.com/hydropower/stories/hohhot-flexible-storage
https://www.gevernova.com/hydropower/stories/hohhot-flexible-storage
https://infra.global/projects/hohhot-pumped-storage-power-station/
https://www.gevernova.com/hydropower/stories/hohhot-flexible-storage
https://www.andritz.com/hydro-en/hydronews/hn36/dinorwig-wales
https://www.andritz.com/hydro-en/hydronews/hn36/dinorwig-wales
https://www.andritz.com/hydro-en/hydronews/hn36/dinorwig-wales
https://web.archive.org/web/20171205093053/http://www.midwesterngovernors.org/EnergyStorage/DTEenergy.pdf
https://www.toshiba.com/taes/services/hydro-turbine-generator-services/rehabilitation-technologies/ludington-pumped-storage-project :
https://www.esru.strath.ac.uk/EandE/Web_sites/17-18/cumbrae/Seawater%20pumped%20hydro.html ; Fujihara et al., 1998
https://www.okinawanderer.com/2016/07/experimental-power-plant-in-kunigami-dismantled/
https://news.cgtn.com/news/2022-06-30/Largest-pumped-storage-power-station-in-E-China-put-into-operation-1bidaYOnK9O/index.html
https://news.cgtn.com/news/2022-06-30/Largest-pumped-storage-power-station-in-E-China-put-into-operation-1bidaYOnK9O/index.html
https://arena.gov.au/renewable-energy/pumped-hydro-energy-storage/
https://etn.news/buzz/us-doe-invests-72-million
https://www.trade.gov/market-intelligence/italy-energy-storage

https://www.rheenergise.com/
https://stateofgreen.com/en/news/water-balloon-tech/
https://www.quidnetenergy.com/solution/#technologySection
https://www.hydropower.org/region-profiles/east-asia-and-pacific
https://greenkogroup.com/ap01.php
https://www.fhc.co.uk/en/power-stations/dinorwig-power-station/
https://www.hydropower.org/factsheets/pumped-storage
https://www.mbrenewables.com/en/pilot-project/
https://www.hydropower.org/publications/enabling-new-pumped-storage-hydropower

Hydropower and Dams, World Atlas, 2022 https://www.hydropower-dams.com/product/2022-world-atlas-industry-guide/

Hydropower and Dams, World Atlas (2022). Japan's water resources, power sector and hydropower development pp 163 - 164.

Huang, X.; Li, Z. (2023) A Comparative Analysis of Two Pricing Mechanisms, MCP and PAB, in the Chinese Frequency Regulation Market. Energies 2023, 16, 2876. https://doi.org/10.3390/en16062876 (https://www.mdpi.com/1996-1073/16/6/2876)

Hydropower & Dams (2024) https://www.hydropower-dams.com/journal/issues-2022/ https://www.hydropower.org/region-profiles/east-asia-and-pacific; USEIA, 2023

IHA (International Hydropower Association) (2024) 2024 World Hydropower Outlook Report (https://www.hydropower.org/factsheets/pumped-storage).

IHA (International Hydropower Association). 2021a. Hydropower Status Report 2021. London. 2021. Available online: https://www.hydropower.org/publications/2021-hydropower-status-report (accessed on 9 Jan 2024).

IHA 2021b, Innovative Pumped Storage Hydropower Configurations and Uses Capabilities, Costs & Innovation Working Group, September 2021

IHA (2018), "The world's water battery: Pumped hydropower storage and the clean energy transition", www.hydropower.org/publications/ the-world's-water-battery-pumped-hydropowerstorage-and-the-clean-energy-transition.

Iannunzio, E. (2018), "Wind farm proposed for Kidston Solar Pumped Hydro project", Utility Magazine, 6 April, https://utilitymagazine. com.au/wind-farm-proposed-for-kidston-solarpumped-hydro-project.

Ichimura, S (2020). Utilization of cross-regional interconnector and pumped hydro energy storage for further introduction of solar PV in Japan. Global Energy Interconnection.3 (1), 68-75 (https://www.sciencedirect.com/science/article/pii/S2096511720300323)

IRENA (International Renewable Energy Agency) (2020) INNOVATIVE OPERATION OF PUMPED HYDROPOWER STORAGE INNOVATION LANDSCAPE BRIEF, pp.24 - (https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Innovative_PHS_operation_2020.pdf)

IWP (International Water Power) (2024) China completes world's largest pumped storage hydropower plant - The Fengning pumped storage hydropower plant. (https://www.waterpowermagazine.com/news/china-completes-worlds-largest-pumped-storage-hydropower-plant/#:~:text=With%20Fengning%20now%20online%2C%20China,200%20GW%20of%20installed%20capacity.)

IFPSH (International Forum on Pumped Storage Hydropower). 2021. Innovative Pumped Storage Hydropower Configurations And Uses Capabilities, Costs & Innovation Working Group. Pp. 93

JEPIC (Japan Electric Power Information Center Inc.) (2024) The Electric Power Industry in Japan - 2024. P_P.90 (https://www.jepic.or.jp/en/data/pdf/epijJepic2024.pdf)

Koritarov, V., L. Guzowski, J. Feltes, Y. Kazachkov, B. Gong, B. Trouille, P. Donalek, and V. Gevorgian. 2013a. Modeling Ternary Pumped Storage Units, ANL/DIS-13/07, Argonne National Laboratory, Lemont, IL, Aug.

Koritarov, V., Kwon, J., Ploussard, Q., Balducci, P (2022). A Review of Technology Innovations for Pumped Storage Hydropower, Hydro Wires, US Department of Energy. Pp.160.

Kitsikoudis, V., P. Archambeau, B. Dewals, E. Pujades, P. Orban, A. Dassargues, and M. Pirotton, and S. Erpicum. 2020. "Underground Pumped-Storage Hydropower (UPSH) at the Martelange Mine (Belgium): Underground Reservoir Hydraulics," Energies 13 (14):3512. https://doi.org/10.3390/en13143512

Kumar A, Arora P, Jain H, Sharma AK, Bhosale AC, Rakshit D and Singh R (2023) "Advanced grid-scale energy storage technologies", A study for India, June 2023. Deparment of Hydro and Renewable Energy, Indian Institute of Technology. Pp. 205. (https://iitr.ac.in/Departments/Hydro%20and%20Renewable%20Energy%20Department/static/special_publ/Advanced_grid-scale_energy_storage_technologies_Nov_2023_HRED_IIT_Roorkee.pdf)

Kumcu, S.Y., Wahidi, A.R. (2019). Pumped-Hydro Energy Storage Alternative Site Evaluation: A Case Study in Turkey. J. Int. Environmental Application & Science, Vol. 14(3): 70-74

Lu, B., Blakers, A., & Stocks, M. (2017). 90–100% renewable electricity for the South West Interconnected System of Western Australia. Energy, 122, 663–674. doi:10.1016/j.energy.2017.01.077

Madlener, R., and J.M. Specht. 2020. "An Exploratory Economic Analysis of Underground Pumped-Storage Hydro Power Plants in Abandoned Deep Coal Mines," Energies 13(21):5634. doi:10.3390/en13215634.

MACSE (THE ELECTRICITY STORAGE CAPACITY PROCUREMENT MECHANISM) (2024) - RSE, Italy Pp.10 (https://www.rse-web.it/wp-content/uploads/2024/05/08_MACSE-inglese.pdf)

Ministry of Coal (2023) Coal Ministry to Embark on Developing Pump Storage Projects in de-Coaled Mines Coal India Identifies 20 Abandoned Mines for such Projects Posted On: 10 NOV 2023 4:26PM by PIB Delhi (https://pib.gov.in/PressReleasePage.aspx?PRID=1976167)

Ming Z, Kun Z,DaoxinL, 2013..Overall review of pumped-hydro energy storage in China: statusquo, operation mechanism and policy barriers.Renew Sustain Energy Rev.17,35–43

MoP (Ministry of Power, Government of India) (2024a) Central Electricity Authority (CEA) revamps the approval process to accelerate the development of the Hydro Pumped Storage Plants in the country Posted On: 02 AUG 2024 12:24PM by PIB Delhi (https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2040582#:~:text=It%20is%20worth%20to%20mention,GW%20under%20survey%20and%20investigation)

MoP_CTU (Ministry of Power) Central Transmission Utility(CTU) https://powermin.gov.in/en/content/central-transmission-utilityctu

MoEF&CC(Ministry of Environment, Forest and Climate Change) (2024a) https://environmentclearance.nic.in/report/view_notifications.aspx

MoP (Ministry of Power, Government of India) (2024a) Central Electricity Authority (CEA) revamps the approval process to accelerate the development of the Hydro Pumped Storage Plants in the country Posted On: 02 AUG 2024 12:24PM by PIB Delhi (https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2040582#:~:text=It%20is%20worth%20to%20mention,GW%20under%20survey%20and%20investigation)

MoP (Ministry of Power, Govt. of India), (2023) - 23, National Framework for promoting Energy Storage Systems.Government of India Ministry of Power. Pp17. (https://powermin.gov.in/sites/default/files/webform/notices/National_Framework_for_promoting_Energy_Storage_Systems_August_2023.pdf)

Nikolaos, P.C.; Marios, F.; Dimitris, K. 2023. A Review of Pumped Hydro Storage Systems. Energies, 16, 4516. https://doi.org/10.3390/en16114516

NLDC (National Load Despatch Centre) (2023) Draft Detailed procedure for Tertiary Reserve Ancillary Service (TRAS) in Compliance to the Central Electricity Regulatory Commission (Ancillary Services) Regulations, 2022

NLDC ((National Load Despatch Centre) (2022)) Detailed Procedure for estimation of the Requirement of secondary reserve Ancillary Service (SRAS) and Tertiary Reserve Ancillary Service (TRAS) at Regional Level (on 2nd Dec. 2022) Prepared in Compliance to Central Electricity Regulatory Commission (Ancillary Services) Regulations, 2022 (NLDC, 2022). (https://posoco.in/en/download/detailed-procedure-for-estimation-of-the-requirement-of-secondary-reserve-ancillary-service-sras-and-tertiary-reserve-ancillary-service-tras-at-regional-level/?wpdmdl=49385)

Obermeyer, H., L. George, J. Wells , and R. Robichaud. 2019. "Submersible Pump-Turbine Configuration to Reduce the Civil Costs of Pumped Storage Hydropower, HydroVision International," Portland, OR, July 23–25, 2019.

Papadakis, C.. Nikolaos , Marios, F., 1 Dimitris, L (2023). A Review of Pumped Hydro Storage Systems. Energies, 16(11), 4516;

Pérez-Díaz JI, Cavazzini G, Blázquez F, Platero C, Fraile-Ardanuy J, Sánchez JA, Chazarra M. (2014)Technological developments for pumped-hydro energy storage. Technical Report, Mechanical Storage Subprogramme, Joint Programme on Energy Storage, European Energy Research Alliance, May 2014

Peng, Y., Yang, Y., Chen, M., Wang, X., Xiong, Y., Wang, M., (2023) Value Evaluation Method for Pumped Storage in the New Power System. Chinese Journal of Electrical Engineering, 9 (3): 26 – 37 https://doi.org/10.3390/en16114516 (https://www.mdpi.com/1996-1073/16/11/4516)

Pikl, F.G., W. Richter, and G. Zenz. 2017. "Pumped-storage technology combined with thermal energy storage - Power station and pressure tunnel concept." Geomechanics and Tunnelling 10(5):611–619.

Pikl, F.G., W. Richter, and G. Zenz. 2019. "Large-scale, economic and efficient underground energy storage." Geomechanics and Tunnelling 12(3):251–269.

Pöyry (2014), Pumped Storage Schemes, Pöyry, Vienna, www.poyry.at/sites/www.poyry.at/files/media/related_material/hydro_power_pumpedstorage_brochure_0112014_6.pdf.

Prouvost, B. (2017), "Creating the ultimate hybrid system by mixing solar energy and hydroelectricity", Renewable Energy Focus, 27 April, www.renewableenergyfocus.com/ view/45793/creating-the-ultimate-hybrid-systemby-mixing-solar-energy-and-hydroelectricity.

Raghuvanshi, T.K , (2019). Plane failure in Rock slopes – A review on stability analysis techniques, J. King Saud Univ. – Sci., 31: 101-109 http://www.sciencedirect.com/science/article/pii/S1018364717304470

Raghuvanshi, T.K, Ibrahim,J. and Ayalew, D. (2014). Slope stability susceptibility evaluation parameter (SSEP) rating scheme – An approach for landslide hazard zonation. J. Afr. Earth Sci, 99: 595-612 DOI: http://10.1016/j.jafrearsci.2014.05.004

Rehman, S., Al-Hadhrami, L.M., Mahbub Alam, M. 2015. Pumped hydro energy storage system: A technological review. Renewable and Sustainable Energy Reviews. 44: 586 – 598.

REPA-EF HyFi (2024) White Papers PSps PSEPs/ PSHPs and NHIRED, 100 GW pumped Storage Projects (PSPs) by 2032 and Hydro Energy Resurgence, ENERTiA. PP36

REN21. Renewables 2022 Global Status Report. 2022. Available online: https://www.ren21.net/wp-content/uploads/2019/05/G SR2022_Fact_Sheet_Germany.pdf (accessed on 13 October 2022).

Steffen, B (2011). Prospects For Pumped-Hydro Storage In Germany. EWL Working Paper, No. 07/11 Germany: University of Duisburg-Essen.

Tian, B., He, Y. , Zhou, J., Wang , B., Wang, Y., Shi, W. (2023). Cost-sharing mechanisms for pumped storage plants at different market stages in China. Renewable energy. 217: 119183.

Voith (2019), "Europe's most advanced pumpedstorage plant", http://voith.com/corp-en/ industry-solutions/hydropower/pumped-storageplants/frades-ii-portugal.html

UKPSP (2023) Uttrakhand Pumped Storage Projects policy (https://static.investindia.gov.in/s3fs-public/2024-03/Uttarakhand%20Pumped%20Storage%20Project%20Policy%2C%202023.pdf)

USDE (US Department of Energy) (2023) US Hydropower market Report 2023 Edition, Office of Energy Efficiency and Renewwable Energy, pp.138

Wenxuan Tong, Zhengang Lu, Weijiang Chen, Minxiao Han, Guoliang Zhao, Xifan Wang, Zhanfeng Deng, Solid gravity energy storage: A review, Journal of Energy Storage, Volume 53, 2022, https://doi.org/10.1016/j.est.2022.105226.

Witt, A., B. Hadjerioua, R. Uria-Martinez, and N. Bishop. 2015. Evaluation of the Feasibility and Viability of Modular Pumped Storage Hydro (m-PSH) in the United States, ORNL/TM2015/559, Oak Ridge National Laboratory, Oak Ridge, TN

World Bank Group, ESMAP and SERIS (2019), Where Sun Meets Water: Floating Solar Market Report, World Bank, Washington, DC.

XFLEX HYDRO (2019a), "Frades 2 Portugal", https://xflexhydro.net/frades-2.

XFLEX HYDRO (2019a), "Frades 2 Portugal", https://xflexhydro.net/frades-2.

Zakeri, B.; Syri, S., 2015. Electrical energy storage systems: A comparative life cycle cost analysis. Renew. Sustain. Energy Rev. 201

ANNEEXURE 1: SELECTED PUMPED STORAGE HYDROPOWER PROJECTS FROM VARIOUS COUNTRIES

A1.1

Country:	United States
Status:	Operating (Active)
Coordinates:	38°12′32″N 79°48′00″W
Power Capacity:	3003 MW (6 Units)
Storage capacity:	24000 MWh
Turbine Generators:	Six Francis-type 500-MW units manufactured by Allis Chalmers Maximum Pumping Power (per unit): 642,800 horsepower (479,300 kW)
Water Flow:	Pumping 12.7 million gallons of water per minute; Generating 13.5 million gallons of water per minute.
License issued:	January 1977
Operating since:	December 1985.
Owners:	Dominion Energy (60%), Bath County Energy, LLC (approximately 24%) and Alleghany Power System (approximately 16%).
Lower Reservoir;	Dam: Height - 135 feet; Length - 2,400 feet; containing 4 million cubic yards of earth and rock fill; Surface Area - 555 acres and water level fluctuates 60 feet during operation.
Upper Reservoir;	Dam Height - 460 feet and Length - 2,200 feet, containing 18 million cubic yards of earth and rock fill; Surface area: 265 acres and the water level fluctuates 105 feet during operation.
Web site:	https://www.dominionenergy.com/projects-and-facilities/hydroelectric-power-facilities-and-projects/bath-county-pumped-storage-station

Figure A1.1: Bath County Pumped Storage Station

Cradled in Virginia's rugged Allegheny Mountains, the world's most powerful pumped storage generating station quietly balances the electricity needs of millions of homes and businesses across six states. The Bath County Pumped Storage Station, which went into operation in 1985, is jointly owned by Dominion and the operating companies of the Allegheny Power System, and managed by Dominion Generation. This mammoth station was cited as one of the nation's most outstanding 1985 engineering achievements. The earth and rock fill moved to construct the dams and other project facilities, if piled up, would create a mountain 1,000 feet (305 meters) high. Enough concrete was poured to build 200 miles (322 kilometers) of interstate highway.

The station consists of two large reservoirs — one 1,262 feet (385 meters) higher than the other, a massive power house and the huge tunnels that connect them. When demand is low, water is pumped from the lower reservoir to the upper one. When demand is high, valves permit water to run through the tunnels to the lower reservoir at a rate as high as 13.5 million gallons (852 cubic meters/second) per minute, turning six turbine generators. The water level in the 265-acre upper reservoir can fluctuate as much as 106 feet when the unit is operated. The Bath County Pumped Storage Station is nearly surrounded by the George Washington National Forest and was built in cooperation with the U.S. Forest Service. Occupying a relatively small amount of land, it has had minimal adverse effect on the environment. Flows to both streams, Back Creek and Little Back Creek, are supplemented by storage from the station reservoirs. This significantly improves stream flow during periods of drought and enhances the environment for fish and other aquatic life.

The extreme fluctuations in water levels in the two reservoirs make them unsuitable for recreation. However, a separate 325-acre (1.32 sq. kilometers) public recreation area containing two lakes is located just downstream from the lower dam. The area has facilities for fishing, non-power boating, picnicking, swimming, hiking and camping. The recreation area is open on a seasonal basis only (http://www.dom.com/about/stations/hydro/bath-county-pumped-storage-station.jsp).

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A1.2 Cortes - La Muela hydropower complex

Country:	Spain
Status:	Operational since October 2015
Location:	The Cortes-La Muela hydroelectric power station is located on the right bank of the Jucar River, in the Cortes de Pallás municipality, approximately 85km away from Valencia.
Coordinates:	latitude - 39.2408334; Longitude - -0.94
Power capacity:	290MW Cortes II conventional hydroelectric plant, the 634MW La Muela I and the 878MW La Muela II pumped storage power plants

Opeing date:	Construction of the La Muela I pumped storage power plant was started in 1983, while it started generating power along with the 290MW Cortes II conventional hydroelectric plant in 1989
Turbine:	The La Muela I pumped storage facility is equipped with three reversible turbines of total installed generating capacity of 634MW and total pumping capacity of 540MW. The La Muela II pumped storage plant consists of four reversible Francis pump turbines and can generate 218MW of electricity with a water flow rate of 48m3/s while operating in turbine mode during peak electricity demand. These turbines are housed within a 117m-long, 19.85m-wide and 50m-high underground cavern
Head:	The Cortes II conventional hydroelectric plant is located on the lower reservoir, and the altitude difference between the lower and upper reservoir is 524m
Storage capacity:	24 GWh
Date of Opening:	The expansion of La Muela II pumped storage hydroelectric facility was done in October 2013.
Owner:	Spanish electric utility Iberdrola
Operated by:	Spanish electric utility Iberdrola
Upper Reservoir:	
Lower Reservoir:	Jucar River as the lower reservoir
Project cost:	The La Muela II pumped storage hydroelectric plant was built with an estimated investment of more than 1.2 billion Euros (https://www.iberdrola.com/about-us/what-we-do/hydroelectric-power/hydro-plant-cortes-la-muela)
Power evacuation:	The electricity generated by the Cortes-La Muela hydroelectric power complex is stepped up from 14.5kV to 400kV, and is evacuated into the grid through a 400kV substation operated by public utility Red Eléctrica de España.

Cortes - La Muela hydro scheme, with 1,780 megawatts (MW) installed capacity, is one of Europe's largest pumped-storage hydropower plants, The Cortes-La Muela hydroelectric power station is located on the right bank of the Jucar River, in the Cortes de Pallás municipality, approximately 85km away from Valencia.

Owned and operated by Spanish electric utility Iberdrola, the 1.8GW hydropower complex comprises the 290MW Cortes II conventional hydroelectric plant, the 634MW La Muela I and the 878MW La Muela II pumped storage power plants. With the commissioning of the La Muela II pumped storage hydroelectric facility expansion in October 2013, the power complex is capable of producing 1,625GWh of clean electricity a year, which is enough to meet the annual power demand of approximately 400,000 households. The power complex utilizes the Jucar River as the lower reservoir and an artificial upper reservoir to store water for electricity generation during peak electricity demand. Construction of the La Muela I pumped storage power plant was started in 1983, while it started generating power along with the 290MW Cortes II conventional hydroelectric plant in 1989. The La Muela I pumped storage facility is equipped with three reversible turbines of total installed generating capacity of 634MW and total pumping capacity of 540MW.

The Cortes II conventional hydroelectric plant is located on the lower reservoir, and the altitude difference between the lower and upper reservoir is 524m. The La Muela II pumped storage hydroelectric plant was built with an estimated investment of more than £296m ($390m). Construction on the La Muela II expansion project was started in 2006, while commercial operations started in October 2013. The La Muela II plant consists of four reversible Francis pump turbines housed within a 117m-long, 19.85m-wide and 50m-high underground cavern. Each reversible unit with a 600rpm turbine can generate more than 218MW of electricity with a water flow rate of 48m3/s while operating in turbine mode during peak electricity demand. The power rating of the hydraulic pump of each unit is more than 185MW. Operating in pump mode, each unit can lift water to the upper reservoir at a rate of 36m3/s utilising surplus renewable electricity in the grid. Water flows between the two reservoirs via the underground power station, through an 840m-long, 5.45m-diameter and 45°-inclined penstock, and a conduction tunnel structure. The Cortes-La Muela hydroelectric power facility utilises excess renewable energy generation capacity from solar and wind sources to store water in the upper reservoirs during off-peak hours, especially during night time. It functions as a conventional hydroelectric generation facility utilising the flow of water accumulated in the upper reservoir during peak daylight hours. Apart from delivering low-cost electricity during peak consumption periods, the pumped-storage hydroelectric power complex also plays a key role in grid stabilization in eastern Spain.

Figure AI.2: Cortes - La Muela hydropower complex

Contractors involved with the La Muela II project: Fomento de Construcciones y Contratas (FCC) was engaged for civil construction works, including the erection of underground powerhouse structure as well as the transformer cavern for the La Muela II expansion project. Obras Subterráneas (OSSA), a construction engineering company based in Spain, carried out tunnelling works for the project. Voith Hydro won a €36m contract to supply four reversible Francis turbines and spherical valves in 2008, while French electrical equipment maker Alstom supplied four generators for the project. A consortium of Cavosa, a subsidiary of Sacyr, and Alstom Hydro, was contracted to build the penstock, while Rowa Tunnelling Logistics was sub-contracted for the tunnelling work. Sygma Technologies provided site management, construction supervision and quality management services during the penstock construction. Alfran, a subsidiary of Grupo Aldomer, performed thermal welding treatment work for the penstock. Tamoin was engaged for the assembly of electromechanical equipment, while

Prysmian Group delivered power, instrumentation and control cables for the La Muela II expansion project. Pine Equipos Eléctricos, a subsidiary of Zima Corporation, supplied 12 motor control centre (MCC) switchboards for the project (https://www.nsenergybusiness.com/projects/cortes-la-muela-power-complex/)

The complex consists of the Cortes conventional hydro power plant, and the La Muela pumped storage facility, which houses seven reversible turbines in two underground caverns. The station can use excess power on the grid to pump water from its lower level reservoir to be stored in the upper one, using hydraulic pumps. Then, when energy is required on the system, the water stored in the upper reservoir can be used to generate electricity for customers. As well as being a reliable facility, with availability exceeding 90%, Cortes - La Muela is an extremely flexible asset. It can generate 1,780 MW of electricity for the grid in less than 5 minutes from standstill. In just 30 seconds, each of its nine units can generate 100 MW. With its fast response, and its ability it can quickly switch from pumping mode to generation mode, it also provides stability for the grid. Ultimately La Muela helps to make the most of every green megawatt of power generated from renewable sources. “The La Muela pumped-storage scheme has a crucial role to play to support the energy transition. It stores excess energy on windy and sunny days, that could otherwise be lost, and it can quickly provide power for homes and businesses when they require it." “Pumped-storage also helps to keep the grid system stable.

Power output produced by the wind and sun can change quickly, but fast and flexible stations like Cortes - La Muela have the tools to help keep the system secure.” This type of power station utilises two reservoirs at different altitudes, allowing water to be stored when demand is low and then used to generate energy during peak consumption times, in order to balance overall electricity demand. During off-peak hours, typically nights and windy days, excess generation capacity is used — which also has a lower market cost — to pump water from the lower level (1) reservoir to the upper one by means of hydraulic pumps that propels the water through a penstock (2) and conduction tunnel structure. The upper reservoir (3) acts as a storage facility, where energy is stored as potential energy. At peak hours, i.e. daylight hours or days with low renewable output, the pumping station functions as a conventional hydroelectric plant. Water accumulated in the upper reservoir (4) is sent to the lower reservoir through the conduction tunnel (5). Water potential energy is transformed into mechanical energy in the hydraulic turbine (6), this mechanical energy is transformed in electrical energy in the generator (7), then this electric energy is sent to the grid where it is instantaneously distributed to consumers.
(https://www.eurelectric.org/stories/decarbonisation/cortes-la-muela-pumped-storage)

Contact Resource

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A1.3 Tumut-3 Pumped Hydro project

Country:	Australia
Status:	Operating (Active)
Location:	New South Wales, Australia
Coordinates:	35°36′42″S 148°17′29″E
Power capacity:	1,800 MW (Generating) 600 MW (Pumping)
Turbine:	Francis turbines (6 x 304.3MW); Supplier - Toshiba Energy Systems and Solutions
Generator:	Mitsubishi Electric supplied 6 electric generators for the project.
Net Head:	150.9m
Storage capacity:	921 million cubic meter
Date of Opening:	1974 upgraded 2012
Owner:	The Tumut 3 Pumped Hydro project is owned by Snowy Hydro Limited, a joint venture between the Commonwealth of Australia and the State of New South Wales.
Operated by:	The project is operated by Snowy Hydro Operations Pty Ltd, a wholly-owned subsidiary of Snowy Hydro Limited.
Upper Reservoir:	Tumut Pond
Lower Reservoir:	Blowering Reservoir

https://www.power-technology.com/data-insights/power-plant-profile-tumut-3-australia/?cf-view
https://www.snowyhydro.com.au/generation/the-snowy-scheme/

The Tumut 3 Pumped Hydro project is a major part of the Snowy Mountains Scheme, a large-scale water management and hydroelectricity generation scheme in the Snowy Mountains of New South Wales. The Snowy Mountains Scheme was constructed between 1949 and 1974 and is one of the largest engineering projects ever undertaken in Australia. Tumut 3 Power Station is a pumped-hydro facility which is capable of generating and pumping by recycling water between Talbingo Reservoir and Jounama Pondage. It was the first major pumped-hydro plant built in Australia and remains the largest such facility in Australia today. After the Scheme was built, two new small hydro stations were constructed on existing Snowy Scheme dams: Jindabyne Mini Hydro Power Station, on Jindabyne Dam, and the Jounama Small Hydro Power Station, on Jounama Dam, to capture the otherwise wasted energy of water releases from these storages. The eight hydro Snowy power stations comprise 33 turbines with a total generating capacity of 4,100 megawatts (MW) and produce on average, 4,500 GWh of renewable electricity each year.

Figure A1.3: Tumut 3 Pumped Hydro Power Station

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A1.4 Kokhav Hayarden Pumped Storage Hydropower Project

Country:	Israel
Status:	Under construction
Location:.	near the Jordan Star (Kokhav Hayarden) National Park in Israel
Coordinates:	32.601733°N 35.517283°E
Power capacity:	344 MW
Turbine:	The Kokhav Hayarden pumped storage plant will be equipped with two General Electric (GE) 172MW Francis turbines and pump units in an underground powerhouse cavern.
Generator:	Voith Hydro Holding supplied 4 electric generators for the project. The generator capacity is 425 MVA.
Head:	450m
Storage capacity:	3 million cubic metres (Mcm)
Headrace:	The underground waterways include a 755m-long and 5.5m-diameter, concrete-lined headrace tunnel,
Penstock:	A 670m-high and 4m-diameter steel penstock,
Tailrace:	A 1.6km-long and 5.5m-diameter tailrace tunnel.
Other components:	The project involves a total of 5.5km of underground tunnels, as well as a transformer cavern, along with a 161kV switching station and other auxiliary systems on the surface.

:

Owner:	Hutchison Water, a subsidiary of Hong Kong-based CK Hutchison Holdings, in partnership with Noy Fund, a privately-held energy and infrastructure investment company based in Israel, is developing the project through a special purpose company (SPC) named Star Pumped Storage.
Operated by:	
Upper Reservoir:	Dam - Earthfill ; 25m-high and 1.8km-long; earthfill upper dam; Storage - three million cubic metres (Mcm)
Lower Reservoir:	Dam - rockfill concrete dam measuring 1.7km long and 18m high; Storage - three million cubic metres (Mcm)
Project cost:	$600m
Power evacuation:	The electricity generated by the Kokhav Hayarden pumped storage power plant will be evacuated into the Israeli power grid through a 161kV transmission line.
Financing:	The Kokhav Hayarden hydropower project is being financed through a consortium of two Israeli banks, namely Hapoalim and Leumi.

The Kokhav Hayarden power project is a 344MW pumped storage hydroelectric power station under construction near the Jordan Star (Kokhav Hayarden) National Park in Israel. The Kokhav Hayarden pumped storage hydroelectric facility is located in Kokhav Hayarden near Beit She'an, approximately 120km away from Tel Aviv, in north-eastern Israel. The project site lies in the Gilboa Mountains, approximately 20km away from the Gilboa pumped storage facility that began operations in 2020. It will also become the lowest power plant of such kind in the world, as the powerhouse lies 275 meters below sea level, according to building contractor Power Construction Corporation of China (PCCC) (https://www.globaltimes.cn/page/202210/1276660.shtml). Hutchison Water, a subsidiary of Hong Kong-based CK Hutchison Holdings, in partnership with Noy Fund, a privately-held energy and infrastructure investment company based in Israel, is developing the project through a special purpose company (SPC) named Star Pumped Storage. The £422m ($600m) project is being developed on a design-build-own-operate (DBOO) basis. The construction works on the project were started in December 2016, with the start of commercial operations expected by 2021. Once operational, the Kokhav Hayarden pumped storage facility, together with the nearby 300MW Gilboa pumped storage power plant, is intended to provide flexible back-up power and stability to the National Grid of Israel.

The pumped storage project features a 25m-high and 1.8km-long earthfill upper dam, while the lower dam will be a rockfill concrete dam measuring 1.7km long and 18m high. The upper and lower reservoirs of the project will have a water storage capacity of three million cubic metres (Mcm) each. The difference in height between the reservoirs will be 450m.

Contractors Involved: A joint venture of Chinese state-owned Sinohydro and Powerchina Huadong Engineering is the engineering, procurement, and construction (EPC) contractor for the Kokhav Hayarden pumped storage power project.

GE Renewable Energy was awarded a turnkey contract for the design, manufacturing, supply, and installation of the entire electro-mechanical and hydromechanical equipment along with the balance of plant (BOP) equipment for the project in August 2017. The contractual scope also includes a 20-year operation and maintenance agreement for the plant. Hutchison Water engaged Pietrangeli to provide engineering services during the feasibility study, final design, and the preparation of the tender documents for the project in 2013.

The Sinohydro and Huadong Engineering joint venture subcontracted Geodata for the geoengineering design consultancy services, while the Grenoble Institute of Technology (Grenoble INP) of France was engaged for performance acceptance tests (PAT) services for the project.

Beijing SOIL Instruments supplied geotechnical monitoring equipment, while Israel-based ADI Measurement and Engineering provided automatic total station (ATS) devices to monitor irregular trends during excavation works for the project.

QAONLINE developed project management information and quality management systems.

https://www.nsenergybusiness.com/projects/kokhav-hayarden-pumped-storage-hydropower-project/

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Hutchison Water 300 Beach Road, #39-01/04 The Concourse Singapore 199555 Email: ilap@hutchison-water.com	QAONLINE developed project management information and quality management systems. Possible source of information for Kokhav Hayarden PSP QAONLINE 2014 Ltd, Carmelim Building, Yozima 3, Tirat Carmel. Email: office@qaonline.co.il

A1.5 Manara Pumped Storage Plant, Israel

Country:	Israel
Status:	Under construction
Location:.	in the Upper Galilee adjacent to the Lebanese border and overlooking the Hula Valley, it falls under the jurisdiction of Upper Galilee Regional Council.
Coordinates:	33.1898, 35.5555 (WGS 84)
Power capacity:	156 MW (Single unit)
Turbine:	Voith pump turbine (156 MW) https://voith.com/corp-en/news-room/press-releases/2021-02-22-vh-voith-wins-major-orders-for-pumped-storage-plants.html
Owner:	Israel Electric Corporation (IEC) Ellomay Capital LTD [83.333%]; Ampa Investments LTD [16.667%][
Upper Reservoir:	active storage of 1.2 Mio. m³
Lower Reservoir:	active storage of 1.24 Mio. m³.
Powerhouse:	The powerhouse is situated in a cavern inside the mountain hills and includes one pump-turbine, one motor-generator and a step-up transformer with a total installed capacity of 156 MW.

Manara is a situated in northern Israel. Located in the Upper Galilee adjacent to the Lebanese border and overlooking the Hula Valley, it falls under the jurisdiction of Upper Galilee Regional Council. The Manara Pump Storage Project will have an installed capacity of 156 MW (single 156 MW unit). The design of the system is compliant with a daily cycle (generation and pumping). The project includes one pump-turbine unit that is able to convert the hydraulic energy into electric energy and vice-versa.

The pump-turbine is capable of fully automatic operation and of providing several operating modes and capabilities. In turbine operation, the pump-turbine is suitable for frequency control within all the load range. The upper reservoir with an active storage of 1.2 Mio. m³ is designed as daily reservoir.

Figure A1.4: Manara Pumped Storage Plant, Israel

The power water way with a length of round 1,100 m and 3.0 m diameter is connected to the lower reservoir with an active storage of 1.24 Mio. m³.The powerhouse is situated in a cavern inside the mountain hills and includes one pump-turbine, one motor-generator and a step-up transformer with a total installed capacity of 156 MW.

AFRY's assignment covers Owner's Engineering services for Ellomay PS Ltd. It will be an important role to ensure timely, cost and quality fulfilment for the Owner, working closely with the EPC Contractor, Electra Infrastructure Ltd. Beside the site activities, AFRY will review the full design and will support the Client during the commissioning of the project. The overall schedule for AFRY's services is about 60 months. This is a continuation of AFRY's outstanding experience in the development and design of PSPP globally. Engineering consultancy Dr Sauer & Partners will provide detailed design for underground elements of the project. The entire start / stop, dewatering, coupling, operation and synchronization will be automatically controlled by means of computerized controllers, connected to indicators and sensors on the systems and motors, in order to ensure correct operation as high level of availability, reliability and maintainability is required in order to satisfy the IEC grid requirement.

Contact Resource:

https://afry.com/en/project/manara-pumped-storage-plant-israel-green-battery-iec : https://afry.com/en/competence/pumped-storage-power-plants	Mr.Kalia Weintraub, CFO Ellomay PS Ltd.: Tel: +972 (3) 797-1111 Email: hilai@ellomay.com SOURCE: Ellomay Capital Ltd https://ellomay.com/under-construction/	Dr. Sauer & Partner GmbH. Sterneckstrasse 35/III 5020 Salzburg Austria. T: +43 (0) 662 879 999. :F: +43 (0) 662 878 999. E: salzburg@dr-sauer.com

A1.6 Okutataragi Pumped Storage Power Station

Country:	Japan
Status:	Operating (Active)
Location:	Tataragi, Asago City, Hyogo Prefecture, Japan
Coordinates:	35°14′12″N 134°51′23″E
Power Capacity:	1932 MW Maximum plant output: At vegining 1212MW (303MW×4units), later unit No.5 and 6 (360MW×2units) were introduced
Net Head:	388m
Storage Capacity:	15,546 MWh
Construction started:	1970
Operation started:	July 1975
Upper Reservoie:	Kurokawa Reservoir; storage capacity - 33,387,000 m3
Lower Reservoir:	Tataragi Reservoir: storage capacity - 19,440,000 m3
Owner:	The Kansai Electric Power Co., Inc. (KEPCO)

Okutataragi is the largest pumped storage hydropower plant in Japan and one of the largest in the world, a very impressive plant that covers peak electricity needs at the times when this is most needed. Despite its very large size of the pumped storage hydropower plant Okutataragi located in Asago, Hyogo Prefecture, its surrounding nature, rivers and forests are captivating (https://www.eps.rs/eng/vesti/Pages/45-23.aspx).

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Research Article: Yokoyama, Y., Yamamoto, K., Tani, K. (2019) Renovation of the pumped-storage system from fixed speed to adjustable speed at Okutataragi power station. 29th IAHR Symposium on Hydraulic Machinery and Systems. IOP Conf. Series: Earth and Environmental Science 240 (2019) 082004. doi:10.1088/1755-1315/240/8/082004

A1.7 Raccoon Mountain Pumped-Storage Plant

Country:	United States
Status:	Operational (Active)
Location:	Marion County, west of Chattanooga in the U.S. state of Tennessee.
Coordinates:	35°02′55″N 85°23′48″W
Power capacity:	1652 MW
Turbine:	Voith Hydro Holding was selected as the turbine supplier for the hydro power project. The company provided 4 units of pump turbines, each with 392MW
Generator:	Voith Hydro Holding supplied 4 electric generators for the project. The generator capacity is 425 MVA.
Head:	320m
Storage capacity:	36,344 MWh
Date of Opening:	1978
Owner:	Tennessee Valley Authority
Operated by:	Tennessee Valley Authority
Upper Reservoir:	Dam – Embankment; Height – 70m, Length – 2800m, Fill volume -
Lower Reservoir:	Dam – Gravity; Height – 25 m, Length - 1,148 m; Active capacity - 39,634,000 m3
Project cost:	

https://www.tva.com/energy/our-power-system/hydroelectric/raccoon-mountain
https://www.power-technology.com/data-insights/power-plant-profile-raccoon-mountain-us/?cf-view

The Raccoon Mountain project is TVA's largest hydroelectric facility. Water is pumped to the reservoir on top of the mountain and then used to generate electricity when additional power is needed by the TVA system. Raccoon Mountain Pumped-Storage Plant is located in southeast Tennessee on a site that overlooks the Tennessee River near Chattanooga. The plant works like a large storage battery. During periods of low demand, water is pumped from Nickajack Reservoir at the base of the mountain to the reservoir built at the top. It takes 28 hours to fill the upper reservoir. When demand is high, water is released via a tunnel drilled through the center of the mountain to drive generators in the mountain's underground power plant.

The area around Raccoon Mountain is a state-designated Wildlife Observation Area. The mountaintop is home to whitetail deer, woodchucks, gray foxes and, of course, raccoons. The most compelling wildlife attraction of the area is a large wintering population of bald eagles, which can be sighted from the overlook as they hunt in the woods and waters. The adjacent day-use area offers more than 28 miles of mountain biking trails—with names like Live Wire, Megawatt, Switch Yard and High Voltage—for riders of all abilities, as well as a bike-washing station. The trails are open to hikers as well.

Figure A1.5: Raccoon Mountain Pumped-Storage Plant, United States

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A1.8 Grand'Maison Pumped hydropower project

Country:	France
Status:	Operational (Active)
Location:	Vaujany of Isère within the French Alps
Coordinates:	45°12′21″N 06°07′01″E
Power capacity:	1800 MW
Turbine:	The below-ground level contains eight 150 MW Francis pump turbines which can be used for both power generation and pumping. Turbine supplier: GE Renewable Energy
Generator:	GE Renewable Energy supplied 12 electric generators for the project. The generator capacity is 170 MVA.
Net Head:	955m
Storage capacity:	34,800 MWh
Date of Opening:	1987
Owner:	Électricité de France (EDF)
Upper Reservoir:	Dam – Embankment Type; Height – 140m, Length – 550m; Fill Volume:12,000,000 m3

https://www.power-technology.com/marketdata/power-plant-profile-grand-maison-france/?cf-view

The Grand'Maison pumped storage hydropower schemes are a complex of two hydroelectric power stations located in the French Alps, near the town of Le Bourg-d'Oisans. The complex is owned and operated by Électricité de France (EDF), the French national electricity company.

The Grand'Maison schemes consist of two reservoirs, the upper reservoir being located at an elevation of 1,850 meters (6,070 feet) and the lower reservoir at an elevation of 750 meters (2,460 feet). The two reservoirs are connected by a series of tunnels and pipes, which allow water to flow between them. When there is excess electricity available, such as during periods of low demand, the water is pumped from the lower reservoir to the upper reservoir. This process is known as "pumping mode." When there is a high demand for electricity, the water is released from the upper reservoir to the lower reservoir, generating electricity as it flows through the turbines. This process is known as "generating mode."

The Grand'Maison schemes have a total installed capacity of 1,800 megawatts (MW), making them one of the largest pumped storage hydropower complexes in the world. The schemes provide a valuable source of renewable energy for France, and they help to balance the grid by storing excess electricity when demand is low and generating electricity when demand is high. Landry,C., Nicolet, C., Badina, C., Pichon, H., and Drommi, J.L. (2022). Contribution for the roadmap of hydraulic short circuit implementation: Case of Grand-Maison pumped storage power plant. 31st IAHR Symposium on Hydraulic Machinery and Systems. IOP Conf. Series: Earth and Environmental Science 1079 – 012107. doi:10.1088/1755-1315/1079/1/012107 https://iopscience.iop.org/article/10.1088/1755-1315/1079/1/012107/pdf

The Grand’Maison power plant is the largest PSP in Europe with 1.8 GW available in turbine mode for a gross head of 922 m and 1.2 GW in pump mode. The power plant is split in two levels (see figure 1a): the first level above the downstream reservoir features 4 Pelton turbines of 156 MW each (currently updated to 170 MW); the second level, underground, features 8 reversible pump-turbines of 156 MW each.

A trifurcation distributes the flow from the upper gallery to three penstocks that feeds a different number of Pelton turbines and reversible pump-turbines. The two lateral penstocks, referred as CF1 and CF3 in figure 1b, feed one Pelton turbine and three pump-turbines respectively. The central penstock, CF2, feeds two Pelton turbines and two pump-turbines.

The surge tank is located close to the trifurcation as shown in figure 1a. In each penstock, a bifurcation allows distributing the flow either to the Pelton turbine or the pump-turbines. As the number of Pelton turbines and pump-turbines is the same for the lateral penstocks CF1 and CF3, the geometry of the bifurcation is also the same. For the central penstock, the geometry of the bifurcation is different (Decai et al., 2022).

Contact Resource:

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Research Article: Decai, J., Drommi, J.L., Avellan, F. and Allign´e, C. M. (2022). CFD simulations of hydraulic short-circuits in junctions, application to the Grand’Maison power plant. 31st IAHR Symposium on Hydraulic Machinery and

sebastien.duchamp@ge.com +33 6 73 19 59 64	Systems, IOP Conf. Series: Earth and Environmental Science 1079 (2022) 012106. doi:10.1088/1755-1315/1079/1/012106

A1.9 Ingula pumped storage plant

Country:	South Africa
Status:	Operational since 2017
Location:	in the escarpment of the Little Drakensberg range straddling the border of the KwaZulu-Natal and Free State provinces, South Africa. It is about 22 km (14 mi) North-East of Van Reenen.
Coordinates:	28°16′54″S 29°35′08″E
Power capacity:	1332MW
Opeing date:	2017
Turbine:	4 x 333 MW Francis Pump type turbine
Head:	480m
Storage capacity:	26,300,000 m3
Owner:	Eskom and CMC Impregilo Mavundla
Operated by:	
Upper Reservoir:	Dam – Concrete faced rock fill dam; Height -39m Bedford Reservoir; Storage capacity; 22,400,000 m3
Lower Reservoir:	Dam - roller-compacted concrete gravity dam Height – 41m.Bramhoek Reservoir; Stoage capacity; 26,300,000 m3
Headrace:	A 2 km long headrace tunnel connects the upper reservoir to the underground power station which houses 4 x 333 MW (447,000 hp) reversible Francis pump-turbines.
Tailrace:	Water from the power station is discharged down a 2.5 km long tailrace tunnel to the lower reservoir.
Project cost:	US$3.5 billion

The Ingula Pumped Storage Scheme (previously named Braamhoek) is a pumped-storage power station in the escarpment of the Little Drakensberg range straddling the border of the KwaZulu-Natal and Free State provinces, South Africa. It is about 22 km (14 mi) North-East of Van Reenen. The scheme is being built on a 9,000ha site by state-owned Eskom at a cost of R8.9bn. Development of the pumped storage scheme was proposed in 2002 and was initially called the Braamhoek scheme, named after a tributary of the Klip River. In March 2007, the scheme was renamed Ingula, which means the cream on the surface of milk. The basic design of the scheme began in 2004, when it was given environmental clearance. The scheme construction encompasses two dams – the upper and lower reservoirs; a powerhouse, two tunnels that carry water from the reservoirs to the powerhouse, access roads and transmission lines. The upper dam of Ingula PSS, named Bedford Dam, is located in the secondary of Wilge River that flows into the Vaal River system. The dam is 810m long and 40.9m high. It also has a 100m-long emergency spillway, a dam crest with elevation of 1740.6m and 8m crest width. The roller lower dam, named Braamhoek Dam, is situated in the secondary of Klip River that flows into the Thukela River. The length and crest width of the dam are 331m and 5m. The dam is 38.6m high and has a 40m long crest. The 0.5m dam wall height holds flood inflows to avoid 1:200-year flood dam spill. The two dams are situated 4.5km apart. In order to generate electricity during high energy consumption, the water will be pumped from the upper dam to the lower dam. The process will be vice versa during low energy consumption period. A generator is being installed to draw more electricity to drive the water back to upper dam, during the low energy consumption period.

The dams are designed for a water capacity of 22 million cubic metres and have underground waterways. The underground powerhouse comprises four 333MW pump turbines and will generate a total of 1,332MW of electricity. The power house is 172m long and has a height of 40m while its average width is 23m. The water to be stored in the dam will be drawn from the rivers. Ingula PSS has the capacity to generate 1,332MW of electricity. A $70m^3/s$ of maximum discharge capacity is being provided by the Bedford Dam at full supply level, while $52m^3/s$ at minimum operating level. The Braamhoek dam provides a maximum discharge capacity of $74m^3/s$ and $2.3m^3/s$ at high flow and low flow outlets respectively. The Ingula pumped storage plant is built close to the city of Ladysmith in eastern South Africa. This region contributes a major share to the country's electricity generation. The Bedford Stream will serve as an upper reservoir and will be connected to the power house by a headrace tunnel of around two kilometers in length. A tunnel of similar length will be built in the tailrace area to lead the water into a lower reservoir towards the Braamhoek River. With commissioning in 2013, Ingula's four pump-turbine units will significantly contribute to grid stabilization by pumping water from excess electricity during low demand periods to the upper reservoir and releasing for peaking energy generation.
https://voith.com/corp-en/Hypower_18.pdf; https://www.power-technology.com/projects/ingula-scheme/

Contact Resource:

Ingula pumped storage scheme, South African, Voith Hydro for the equipment supply
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A1.10 Los Reyunos Pumped Hydro Storage

Country:	Argentina
Status:	Operational (Active)
Location:	It is located on Diamante river/basin in central Mendoza Province, 35 km from the city of San Rafael Argentina. .
Coordinates:	-34.59o (Lat.); -68.67o (Long.); 34°36′8.45″S 68°38′30.06″W
Power capacity:	224 MW
Opeing date:	1980
Turbine:	CKD Blansko Holding was selected as the turbine supplier for the hydro power project. The company provided 2 units of Francis turbines, each with 118MW nameplate capacity.
Genetor:	Doosan Skoda Power supplied 2 electric generators for the project. The generator capacity is 128 MVA. https://www.power-technology.com/marketdata/los-reyunos-argentina/?cf-view

Owner:	Hirdroeléctrica Diamante (HIDISA)/ Hidroeléctrica de los Nihuiles (HINISA)
Operated by:	Hirdroeléctrica Diamante S.A. (HIDISA)
Upper Reservoir:	Dam - Los Reyunos Embankment dam; height – 130m on Diamante River; reservoir covering an area of 7.40 km2.
Lower Reservoir:	El Tigre Reservoir 2 km downstream.

The Los Reyunos Dam is an embankment dam on the Diamante River, in central Mendoza Province, Argentina, some twenty-two miles (thirty-five kilometers) from the city of San Rafael. The dam, built of stone and compacted clay to minimize execution and cost, is 440 feet (130 meters) high and contains a reservoir covering an area of 1,828 acres (7.40 km2). The dam is used to generate hydroelectricity. This is done with a pumped-storage power station located below the level of the reservoir. About one mile (two kilometer) downstream is a smaller, compensation dam, which forms the lower reservoir, called El Tigre. During the hours of decreased power demand, water is pumped from the reservoir of El Tigre back into Los Reyunos to stabilize the water level. The reservoir is employed in raising Salmonidae and silverside, allowing for sport fishing. Los Reyunos Fishing and Nautical Club, along with private summer residences and a hotel, lies on the western shore of the reservoir and serves as a base for activities in the lake (such as windsurf, canoeing) and in the surrounding mountains (such as hiking).

Contact Resource:

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A1.11 Nant de Drance Pumped Hydro Storage Power

Country:	Switzerland
Status:	Operating
Location:	Finhaut, Saint-Maurice, Valais
Coordinates:	46.1025948; 7.08
Power capacity:	900 MW, energy storage capacity of 20 GWh
Opeing date:	1.1.2022
Turbine:	6 x 150 MW reversible Francis turbine-generators
Penstock:	a series of 425 m long penstocks
Generator:	
Head:	295 m
Owner:	Nant de Drance SA a consortium of Alpiq (39%), SBB (36%), Industrielle Werke

	Basel [de] (15%) and Forces Motrices Valaisannes [fr] (FMV) (10%).
Operated by:	
Upper Reservoir:	Lac du Vieux Emosson; The upper reservoir for the plant, Lac du Vieux Emosson, is formed by a 45 m tall and 170 m long arch dam originally completed in 1955. The dam is undergoing a raising and will be 65 m tall when done. When raised, Lac du Vieux Emosson's storage capacity will be doubled and it will withhold 25,000,000 m3 and have a surface area of 55 ha When full, the upper reservoir will lie 2,225 m above sea level.
Lower Reservoir:	Lac d'Emosson; 227,000,000 m3. The lower reservoir, Lac d'Emosson, is formed by the 180 m tall, 555 m long Émosson Dam, an arch dam which was completed in 1974. It withholds a reservoir with a storage capacity of 227,000,000 m3 and surface area of 327 ha. The lower reservoir is 4 km (2.5 mi) long and when full, lies 1,930 m (6,330 ft) above sea level.
Power evacuation:	
Cost:	US$2.1 billion (CHF 1.9 billion, €1.5 billion)

The Nant de Drance Hydropower Plant is a pumped-storage power station in the canton of Valais in Switzerland. It is within the municipality of Fin haut, district of Saint-Maurice and about 14 km southwest of Martigny. Construction on the power plant began in 2008 and it began operations in 2022. It is owned by Nant de Drance SA, a consortium of Alpiq (39%), SBB (36%), Industrielle Werke Basel [de] (15%) and Forces Motrices Valaisannes [fr] (FMV) (10%). The US$1.9 billion plant has installed capacity of 900 MW and an energy storage capacity of 20 GWh.

Under the guidance of AF-Consult Switzerland Ltd as general planner, the civil engineering works were carried out by GMI (a joint venture of Marti and Implenia) and the electro-mechanical works are being undertaken by GE Hydro.
Contact Resource: GE Renewable Energy - https://www.ge.com/renewableenergy/contact-us

A1.12 Wehr Pumped Storage Power Plant

Country:	Germany
Status:	Operational (Active)
Location:	It is located on Rhine river/basin in Baden-Wurttemberg, Germany.
Coordinates:	47.63; 7.91
Power capacity:	910 MW
Opeing date:	1.1.1976
Turbine:	Andritz Hydro, 4 units of francis turbines, each with 227.5MW 910 MVA in turbine mode and 980 MW in pump mode
Generator :	Voith Hydro Holding supplied 4 electric generators for the project. The generator capacity is 300 MVA.
Head:	625m (630 m of elevation separate the two reservoirs)

Owner:	RWE Power, EnBW Energie Baden-Wurttemberg, Energiedienst and Energiedienst Holding are currently owning the project having ownership stake of 50%, 37.5%, 7.5% and 5% respectively
Operated by:	Schluchseewerk AG
Upper Reservoir:	Hornberg basin of 4.4 million m3
Lower Reservoir:	Wehra basin with a capacity of 4.3 million m3.

RWE Power, EnBW Energie Baden-Wurttemberg, Energiedienst and Energiedienst Holding are currently owning the project having ownership stake of 50%, 37.5%, 7.5% and 5% respectively. Wehr is a pumped storage project. The hydro reservoir capacity is 4.4 million cubic meter. The gross head of the project is 625m.

Development status: The project construction commenced in 1968 and subsequently entered into commercial operation in 1976.

Contractors involved

Andritz Hydro was selected as the turbine supplier for the hydro power project. The company provided 4 units of francis turbines, each with 227.5MW nameplate capacity. Voith Hydro Holding supplied 4 electric generators for the project. The generator capacity is 300 MVA. Since the end of 2021, the world's most powerful horizontal air-cooled motor generator has been in commercial operation at the Wehr pumped storage plant in Germany. The successful commissioning of the new generator — allowing the plant to produce clean energy once again — marks the end of a very challenging project. Providing about 1,000 GWh of clean and renewable energy per year, the pumped storage plant was originally built in the 1970s and has a total capacity of about 910 MVA in turbine mode and 980 MW in pump mode. With its four generating units, it is the biggest power plant in the portfolio of Schluchseewerk AG and provides crucial grid balancing services for Schluchseewerk's owners, EnBW and RWE.

Figure A1.6: Wehr Pumped Storage Power Plant

A short circuit at the B09 generator occurred in September 2019 and a new generator was needed. The owners wanted a robust machine with high availability that could withstand a high number of load changes. After a long R&D design phase and numerous recalculations and simulations, ANDRITZ presented a compelling offer for a new high-efficiency generator. The new generator design was also very daring as the cooling system had been changed from water-cooled to air-cooled, lowering costs, increasing availability and improving maintenance friendliness. The design was very challenging with a nominal voltage of 21 kV, unusual stator bar geometry and the re-use of the existing rotor. ANDRITZ deployed the considerable strengths of the Generator Competence Centers Vienna and Weiz, both in Austria, to enhance the project and they have demonstrated their impressive competence and willingness to think outside the box to deliver an exceptional technological solution. The result is a perfectly optimized product that meets all the customers' needs and requirements.

At the beginning of 2022 a contract for a further generator unit — B10 — was also awarded to ANDRITZ. Bridging grid bottlenecks and black-start capability are two of the most important features of a pumped storage power plant, supporting grid stability with rapid response to changing demand or sudden outages. In Wehr, state-of-the-art units move huge masses of water in a closed and weather-independent cycle between the upper reservoir, the Hornberg basin of 4.4 million m3, and the lower reservoir, the Wehra basin with a capacity of 4.3 million m3. Some 630 m of elevation separate the two reservoirs. Within seconds, electricity can be generated or stored as needed depending on what the power grids demand (https://www.andritz.com/hydro-en/hydronews/hn36/wehr-germany)

Contact Resource:

https://www.andritz.com/feed-and-biofuel-en/locations/mettmann-germany
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A1.13 Shintakasegawa Pumped Storage Power Station

Project Name:	Shintakasegawa Pumped Storage Power Station
Country:	Japan
Status:	Operating
Location:	It is located on Takase river/basin in Nagano, Japan
Coordinates:	Latitude; 36.473841, Longitude; 137.69
Power capacity:	1,280MW,
Opeing date:	1979
Turbine:	4 x 320MW Francis pump turbine Toshiba Energy Systems and Solutions
Generator:	
Head:	140.8 m
Owner:	TEPCO.

Upper Reservoir:	Takase Reservoir; capacity - 76,200,000 m3
Lower Reservoir:	Nankura Reservoi; Capacity - 32,500,000 m3

Shintakasegawa is a 1,280MW hydro power project. It is located on Takase river/basin in Nagano, Japan. The project is currently active. It has been developed in a single phase. Post completion of construction, the project got commissioned in 1979. The project is currently owned by Tokyo Electric Power Co Holdings.

Shintakasegawa is a pumped storage project. The hydro reservoir capacity is 76.2 million cubic meter. The net head of the project is 229m. Toshiba Energy Systems and Solutions was selected as the turbine supplier for the hydro power project. The company provided 4 turbines, each with 320MW capacity.
(https://www.power-technology.com/marketdata/power-plant-profile-shintakasegawa-japan/?cf-view)

The Shin-Takasegawa Pumped Storage Station is a notable example of hydropower projects contributing to Japan's market growth. The station's upper reservoir, formed by the Takase Dam, serves as the water storage for power generation. Standing at a height of 176 meters, the Takase Dam is the tallest in Japan and the second tallest in the country, following the Kurobe Dam. This project exemplifies Japan's commitment to harnessing water resources for clean energy production, providing a reliable source of renewable electricity while minimizing environmental impact through a run-of-river design. Such hydropower initiatives are instrumental in accelerating Japan's overall market growth in the renewable energy sector https://www.giiresearch.com/report/mx1349457-japan-hydropower-market-assessment-by-type-by-size.html

A1.14 Frades II pumped storage power station with variable speed turbines

Project Name:	Frades II pumped storage power station
Country:	Portugal
Status:	Opeating
Location:	It is located about 40 km north-east of Braga, in the northern region of Portugal. Frades II is constructed on the left bank of the Rabagão river, between the Venda Nova and Salamonde reservoirs (https://voith.com/corp-de/2012-10-12_Project_Report_Frades_II.pdf)
Coordinates:	
Power capacity:	780 MW
Opeing date:	2017
Turbine and Generator:	Type of pump - turbines Francis vertical, variable speed. Number of units – 2, Nominal rated output per unit -383 MW, Rated speed – 364 rpm, Rated net head – 414m, Runner diameter – 4.52m Nominal rated flow – 100m3/s Commissioned – 2015. Asynchronous - motor-generators, Rated out put - 419.5 MVA. Rated input -372 MW, Rated voltage – 21 kV
Head:	414m
Owner:	Energias de Portugal (EDP)

The 780 MW PSP project utilizes variable speed turbines with doubly fed induction machine[119].

Figure A1.7 Frades II PSP project in Portugal

Advanced Technology/ Significant Features:

The facility contributes to frequency regulation in a grid with around 20% wind generation[120]. Variable speed machines enable wider operating range, faster response and higher efficiency in PHS plants[121]. It offers additional stability in the event of a drop in voltage, reduces the likelihood of a power failure and enables a fast restart if a power outage does occur[122].

A1.15 KOPS II Pumped Storage Power Station

Project Name:	KOPS II pumped storage power station installed with Ternary systems
Country:	Austria
Status:	Opeating
Location:	It is located inside Vorarlberg, Austrua in Alps, drawing from the same reservoir as the KOPS I hydropower station. The stations are supplied by the Rifa balancing reservoir, located between the tourist centers of Gaschurn and Partenen.

The plant is almost constructed inside the mountains in order to preserve the natural beauty of the Montafon Valley. It has a 5.5 kilometre pressure tunnel, 1.1 kilometre pressure shaft, 140 metre surge shaft, and a new powerhouse located inside a cavern[123].

Advanced Technology/ Significant Features

PSP installed with ternary systems

119 XFLEX HYDRO, 2019a
120 IHA, 2018
121 Voith, 2019; IRENA, 2020
122 https://voith.com/corp-en/industry-solutions/hydropower/pumped-storage-plants/frades-ii-portugal.html
123 https://library.e.abb.com/public/bb6786ddb690f5bbc1257c0d00394087/Project%20Report%20PSP%20KOPS%20II%20(AT).pdf

Figure A1.8 Upper reservoir for Kops II PSP

The three ternary units installed in Kops II allow the parallel operation of the 180 MW turbine and the 150 MW pump (Pöyry, 2014). The Ternary systems, consist of a motor-generator and a separate turbine-and pump set, allow for generation and pumping modes to operate in parallel, which leads to finer frequency control.

This PSP facility is considered fast, as it reaches full load in 20 –30 seconds, enabling it to provide a wider range of ancillary services[124]

A1.16 La Muela Pumped storage power stations

Project Name:	La Muela Pumped storage power stations
Country:	Spain
Statis:	Operational
Location:	The Cortes-La Muela hydroelectric power station is located on the right bank of the Jucar River, approximately 85km away from Valencia. The Cortes-La Muela hydroelectric power station is located on the right bank of the Jucar River, in the Cortes de Pallás municipality, approximately 85km away from Valencia
Opening Date:	2015
Capacity :	1517 MW
Turbine:	Seven reversible turbines
Average annual output:	1625 GWh

La Muela dedicates 40% of its production to ancillary services for real-time system management. The facility’s average annual output of around 1625 GWh is enough to provide the electric consumption of close to 400,000 households[125].

124 IRENA, 2020
125 IRENA, 2020

Figure A1.9: La Muela PSP

A1.17 Kidston Pumped Storage Power Station

Name: Kidston Pumped Storage Power Station (Utilization of Abandoned Mine Pits)
Country: Australia
Status: Under Construction
Location: Kidston, Queensland approximately 280 km north-west of Townsville
Capacity: 250 MW

Design components - an upper reservoir formed by a 20 m high dam around the existing Wises Pit, a lower reservoir utilising the existing Eldridge Pit, a powerhouse cavern with the capacity to generate 250 MW, a tailrace allowing water to pass from the powerhouse to the reservoirs and a spillway from the upper reservoir to the Copperfield River[126].

Kidston PSP is being constructed to generate electricity. The PSP will be coupled with wind and solar PV technology.

Advanced Technology/ Significant Features:
Abandoned Kidston Gold Mine's upper and lower pits.to be used as Reservoirs for PSP.

The projected large-scale hydro 250 MW PHS, with a total of 8–10 hours' storage, would combine a total capacity of 320 MW solar PV and 150 MW wind[127]. The project is expected to provide dispatchable and reliable renewable energy at peak demand, being able to store solar energy during the day and release it during the morning and evening peak periods through the hydro system. It can reduce losses associated with importing electricity from the grid for the PHS scheme, as well as mitigate the risk associated with rising overnight electricity prices when PHS facilities are usually "recharging" (Energy Magazine, 2018). Rapid response (30 seconds) renewable energy.

126 https://www.statedevelopment.qld.gov.au/coordinator-general/assessments-and-approvals/coordinated-projects/completed-projects/kidston-pumped-storage-hydro-project
127 Iannunzio, 2018

Figure A1.10: Kidston Gold Mine's upper and lower pits.to be used as Reservoirs for PSP

A1.18 Grand Maison Pumped Storage Power Station

Name: Grand Maison Pumped Storage Power Station
Country: France; Alqueva, Portugal
Location: It is located on Eau d'Olle river/basin in Auvergne-Rhone-Alpes, France.

Grand Maison PSP with hydraulic short circuit using fixed speed machines and optimised equipment. Fixed-speed pumping will be operated simultaneously with units in generation mode, together with optimisation software for improved flexibility[128].

Figure A1.11: Grand Maison hydropower project

Advanced Technology/ Significant Features:
At Grand Maison, a new Pelton turbine will be used to regulate the load and improve generating efficiency. It will allow frequency response when consuming power from the grid.

At Alqueva, extended unit operation of fixed speed reversible turbines will be tested, targeting an almost continuous power output from zero to rated power.

Both demonstrations will implement advanced software to optimise performance[129]

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128 IRENA, 2020
129 XFLEX HYDRO, 2019c

ANNEXURE 2: PUMPED STORAGE PLANTS IN INDIA - EXISTING AND UNDER CONSTRUCTION

A2.1 Existing PSP Plants

In India ten projects totaling 7,425.60 MW in installed capacity were put into service as PSPs. 8 PSP plants (80%) presently operate in both generating and pumping modes. However, due to operational and development issues, the remaining 2 PSP stations only operate in the generating mode; Nine of these projects are located on the river and one project is Off-River.

(a) PSP plants operating in generation and pumping mode

1. Nagarjunasagar PSP Plant

The Nagarjunasagar PSP Plant (705.6 MW), which was put into service between 1978 and 1985 and is situated close to Vijaypuri in Telangana State's Nalkonda District, was the nation's first PSP plant. The project was put into service in 1978, and several units were put into service from 1978 to 1985. The project uses water from the Krishna River, which has a rated head of 93 meters, to generate electricity. In a 90% reliable year, the project produces 4,000 MU of energy annually. One of the biggest and tallest masonry dams in the world is the multipurpose Nagarjuna Sagar Project (NSP). (CEA, 2023a; Sivakumar et al., 2013).

Table A2.1: Salient Features of Nagarjuna Sagar PSP Project (705.6 MW)

1.	**PSP Name**	Nagarjuna Sagar	12	**Upper Reservoir**	Existing
2	**Status**	Operational		Full Reservoir Level (FRL) (m)	179.832
3	**Type**	On-River (Krshna River)		Max Height of Dam above deepest Foundation (m)	124.663
4	**State**	Telangana		Live Storage (Mcum)	5108
5	**District**	Nalgonda		Gross Storage (Mcum)	8837
6	**Nearest Railhead**	Miryalaguda	13	**Lower Resservoir**	Existing
7	**Coordinates**	Latitude: 16°34'24"N		Full Reservoir Level (FRL) (m)	75.5
		Longitude: 79°18'47"E		Type of Dam	Gravity
8	**Pressure shaft No**	8		Maximum Height above deepest foundation level (m)	Left Side :30.50 Right Side : 31.00
	Length (m)	123.4			
	Diameter (m)	4.88		Live Storage (Mcum	29.55
9	**Tail Race Tunnel**		14	**Powerhouse**	Surface
	Length (m)	148.1		Capacity of each Unit (MW)	7 x 100.8
	Diameter (m)	5.45		Rated Head (m)	97
10	**Annual Energy**	4000		Turbine	Vertical Francis
11	**Estimated Cost (Rs. Crores)**	161.60 (Actual Cost)			

Source: CEA (2023a)

The districts of Guntur, Nalgonda, Prakasam, Khammam, Krishna, and portions of West Godavari receive irrigation water from the Nagarjuna Sagar dam project. Additionally, it generates electricity for the national grid. With an effective capacity of 6.92 cubic kilometers, the dam produced a water reservoir with a gross storage capacity of 11.472 billion cubic meters.

With 26 flood gates that are 13 meters wide and 14 meters high, the dam is 1.6 kilometers long and 124 meters high from its deepest foundation. The states of Andhra Pradesh and Telangana work together to operate it. In order to bring about the Green Revolution in India, a number of massive infrastructure projects known as "modern temples" were started, the first of which was the Nagarjuna Sagar Dam. Additionally, it is among India's first multipurpose irrigation and hydroelectric projects (CEA, 2023a).

2. Kadamparai PSP Project (4 x 100 MW)

In the Coimbatore district of Tamil Nadu, the 400 MW Kadamparai PSP was put into service in 1986, close to the towns of Valparai and Pollachi. The Aliyar River is across from the PSP project. The top reservoir is the Kadamparai dam, while the lower reservoir is the upper Aliyar dam. In order to maximize energy in response to fluctuating demands and spillage compulsions from more natural inflow during rainy seasons, the Kadamparai PSP's operation policies are periodically modified by conditions that define the objective function of either the generation or pumping mode. To determine the operating policies, a variety of system models are provided. (Sivakumar et al., 2020; Loucks, 1992; Wurbs, 1993; CEA, 2023a). The PSP project uses a head of 395 meters to generate electricity and is situated above the Aliyar River. Four Francis Reaction Reversible units, each with a capacity of 100 MW, make up the project's installed capacity. TANGEDCO is in charge of carrying out the project.

Table A2.2: Salient Features of Kadamparai PSP Project (400 MW)

1.	**PSP Name**	**Kadamparai PSP**	12	**Upper Reservoir**	Existing Kadamparai Dam
2	**Status**	Operational		Full Reservoir Level (FRL) (m)	1149
3	**Type**	On-River (Aliyar River)		Max Height of Dam above deepest Foundation (m)	275.53
4	**State**	Tamil Nadu		Live Storage (Mcum)	-
5	**District**	Coimbatore		Gross Storage (Mcum)	1080
6	**Nearest Railhead**	Pollachi	13	**Lower Resservoir**	Existing Upper Aliyar reservoir
7	**Coordinates**	Latitude: 10°23'35.7"N		Full Reservoir Level (FRL) (m)	762
		Longitude: 77°02'40.9"E		Live Storage (Mcum	938
8	**Tail Race**				
	Length (m)	1,476	14	**Powerhouse**	Underground
9	**Head Race Tunnel**			Capacity of each Unit (MW)	4 x 400
	Length (m)	2,480		Head generation (m)	395
10	**Annual Energy (MU)**	-		Turbine	Francis Reaction Reversible
11	**Estimated Cost (Rs. Crores)**	-		Head Pumping (m) (Max)	413

Source: CEA (2023a)

At an elevation of 1,149 meters, the Kadamparai reservoir (the PSP's upper dam) has a gross storage capacity of 30.8 × 106 m² and a live storage capacity of 26.8 × 106 m³. The dam's height is 67.5 meters, and its crest length is 808 meters. 518 m3/sec is the greatest flood discharge. In order to produce a pool for a pumped storage operation at Kadamparai Reservoir, the natural flow of the main stream and tributaries of the Aliyar river is redirected by weirs such Vandal dam, Akkamalai dam, and Deviar dam via a 3558-meter diversion tunnel. The tunnel has a maximum discharge capacity of 42.58 m^3/sec. The catchment area has grown from 22.75 km^2 to 83 km^2 as a result of the water being diverted from the weirs (Sivakumar et al., 2020).

3. Bhira PSP Project (150 MW)

In 1927, the TPCL erected the Bhira Hydroelectric Project in Maharashtra's Raigad district. It uses water from the Mulshi Dam to produce electricity. It can generate 300 MU of design energy and has an installed capacity of 150 MW (6 x 25 MW). An further 165 MW PSP Unit was later put into service in Jojobera in 1995 (https://tatapower100.tatapower.com/locationpop/bhira.html).

Table A2.3: Salient Features of Bhira PSP Project (150 MW)

1.	**PSP Name**	**Bhira PSP**	11	**Upper Reservoir**	Existing
2	**Status**	Operational		Full Reservoir Level (FRL) (m)	606.10
3	**Type**	On-River (Mula River)		Max Height of Dam above deepest Foundation (m)	50.6
4	**State**	Maharashtra		Live Storage (Mcum)	747
5	**District**	Raigarh		Gross Storage (Mcum)	570.76
6	**Nearest Railhead**	Mangaon	12	**Lower Resservoir**	Existing Upper Aliyar reservoir
7	**Nearest Airport**	Pune		Full Reservoir Level (FRL) (m)	95.5
8	**Coordinates**	Latitude: 18°31'34.70"N		Live Storage (Mcum	5.5
		Longitude: 73°30'41.15"E	13	**Powerhouse**	Pit Type
9	**Pressure Shaft**			Capacity of each Unit (MW)	150
	Length (m)	Underground – 555 Surface - 1043.40 Pressure shaft - 111.0		Head generation (m)	530
	Diameter (m)	Underground – 3.7 Surface - 3.5 to 3.3 Pressure shaft – 2.95		Turbine	Pelton and Vertical reversible Francis turbine
10	**Head Race Tunnel**		14	**Annual Energy (MU)**	744.12
	Length (m)	100	15	**Estimated Cost (Rs. Crores)**	272 Cr. Rs (As per Original DPR)
	Diameter (m)	4			

Source: CEA (2023a)

Bhira PSP project's upper dam location is located at the Mula River, which is located at latitude 18°31'34.70"N and longitude 73°30'41.15"E. The Mula River is where the lower dam site is situated; its coordinates are 18°27'50.25"N and 73°23'1.79"E. The top reservoir dam, which is 50.6 meters high, is built across the Mula River. The reservoir's full reservoir level (FRL) is 606.1 meters, and its live storage capacity is 747 Mcum. By building a 28-meter-tall dam over the Mula River, the current lower reservoir was created. With a full reservoir level (FRL) of 95.5 meters, the lower reservoir has a live storage capacity of 5.5 Mcum. There is a 4530-meter-long Head Race Tunnel (HRT) with a 1709.4-meter-long pressure shaft and penstock. With a 150MW installed capacity, a turbine uses the gross head of 518 m to generate energy.

To return water from the powerhouse to the river, a 100-meter-long Tail Race Tunnel is available (CEA, 2023a).

4. Srisailam LBPH PSP (6 x 150 MW)

On the border between Mahabubnagar District in Telangana and Kurnool District in Andhra Pradesh, close to Srisailam town, is the Srisailam Dam, which is situated across the Krishna River. In 1981, the project was put into service.The gravity dam was built 300 meters above sea level in the Nallamala Hills, which are situated between the districts of Mahabubnagar and Kurnool. It features 12 radial crest gates and measures 512 m in length and 145 m in height. It has a 616 km^2 reservoir. At its maximum reservoir level of 270 meters above sea level, the project has a live capacity of 178.74 Tmcft. Six 150 MW (200,000 hp) reversible Francis-pump turbines for PSP operation are housed in the left bank underground power station, while seven 110 MW (150,000 hp) Francis-turbine generators are housed on the right bank semi underground power station. Telangana State Power Generation now owns the project. A pumped storage project, Srisailam LBPH PSP produces 1,955 GWh of power. In 2001, the project was put into service. For the hydropower project, Hitachi Mitsubishi Hydro was chosen to supply the turbines. Six sets of 150MW Francis turbines were supplied by the business. Six electric generators were provided for the project by Mitsubishi Heavy Industries[130].

Table A2.4: Salient Features of Srisailam PSP Project (6 x 150 MW)

1.	**PSP Name**	**Srisailam PSP**	12	**Upper Reservoir**	Existing
2	**Status**	Operational		Full Reservoir Level (FRL) (m)	269.75
3	**Type**	On-River (Krishna River)		Max Height of Dam above deepest Foundation (m)	275.53
4	**State**	Telangana		Live Storage (Mcum)	5218
5	**District**	Nagarkarnool		Gross Storage (Mcum)	6111
6	**Nearest Railhead**	Miryalaguda	13	**Lower Resservoir**	Existing
7	**Coordinates**	Latitude: 16°5'05"N		Full Reservoir Level (FRL) (m)	179.8
		Longitude: 78°54'00"E		Type of Dam	Gravity Masonry
8	**Pressure shaft No**	2		Maximum Height above deepest foundation level (m)	125
	Length (m)	377			
	Diameter (m)	12.9		Live Storage (Mcum	5108
9	**Tail Race Tunnel**		14	**Powerhouse**	Underground
	Length (m)	2,297		Capacity of each Unit (MW)	6 x 150
	Diameter (m)	15		Rated Head (m)	82.8
10	**Annual Energy (MU)**	1,500		Turbine	Vertical Francis
11	**Estimated Cost (Rs. Crores)**	3440.12 with price Level			

Source: CEA (2023a)

5. **Ghatghar Pumped Storage Hydropower project (2 x 125 MW)**

Situated on the border of the Thane and Ahamadnagar Districts of Maharashtra State, India, is the 250 MW PSP known as Ghatghar Project. The project was put into service between 2009 and 2010. A lower and an upper reservoir were created by the project's two dams, an upper dam and a lower dam. The lower dam is 86 meters high, while the higher dam is 14.5 meters.

130 https://www.power-technology.com/data-insights/power-plant-profile-srisailam-lbph-psp-india/

On the Pravara River, a tributary of the Godavari River, sits the 15-meter high Ghatghar dam. The hydro reservoir capacity of the Ghatghar PSP is 3.21 million cubic meters, and its net head is 385.6 meters [131].
With two 125 MW units and a 250 MW installed capacity, the powerhouse produces 454.48 MU of energy annually. The Project is In Operation and it is executed by MAHAGENCO. (CEA, 2023a). The project is highly relevant since it aligns with India's development policy, which prioritizes a stable electricity supply, and with both national and state needs. The project largely produced the intended effects, and some positive impacts on the socio-economic development of Maharashtra are also perceived; therefore, the project's effectiveness is also high, according to the indicators that show the quantitative effects of the Ghatghar pumped storage hydropower station, such as comprehensive circulating efficiency (CCE), operating hours, operation records during peak hours, etc. [132].

Table A2.5: Salient Features of Ghatghar PSP Project (2 x 125 MW)

1.	**PSP Name**	**Ghatghar PSP**	11	**Upper Reservoir**	Existing
2	**Status**	Operational		Full Reservoir Level (FRL) (m)	756
3	**Type**	On-River (Pravara/Shai Nalla)		Max Height of Dam above deepest Foundation (m)	757.50
4	**State**	Maharashtra		Live Storage (Mcum)	5.15
5	**District**	Ahmed Nagar/ Thane		Gross Storage (Mcum)	5.83
6	**Nearest Railhead**	Asangaon	12	**Lower Resservoir**	Existing
7	**Nearest Airport**	Mumbai		Full Reservoir Level (FRL) (m)	346
8	**Coordinates**	Latitude: 19°32'30’’N		Live Storage (Mcum	2.728
		Longitude: 73°40'00"E	13	**Powerhouse**	
9	**Pressure Shaft**			Capacity of each Unit (MW)	2 x 125
	Length (m)	722		Head generation (m)	680
	Diameter (m)	4.25		Turbine	Reversible Vertical Francis
10	Tail Race		14	**Annual Energy (MU)**	
	Length (m)	590	15	**Estimated Cost (Rs. Crores)**	118460
	Diameter (m)	6			

Source: CEA (2023a)

6. Purulia PSP Project (4 x 225 MW)

Four Francis pump-turbine units, each with a 225 MW installed capacity, make up the Purulia PSP project. The project is situated in Bagmundi, West Bengal, India's Purulia District. The project is situated in the Ajodhya Hills on Kistobazar Nullah, a tributary of Sobha Nullah. The project was supposed to be put into service in 2002–2003, but it was delayed due to litigation during the tender stage and issues obtaining clearance for forest area. The project received loan assistance from the Japan International Cooperation Agency (JICA) of ₹2,272 crore, or US$410 million in 2023. The project was opposed by the local villagers, who claimed that hundreds of

131 https://www.power-technology.com/marketdata/ghatghar-psp-lower-india/
132 https://www2.jica.go.jp/en/evaluation/pdf/2012_ID-P53_4_f.pdf

them lost their jobs and that there was a significant loss of vegetation in the area [133]. The main structures involved in the project are two Rockfill dams (Upper and Lower Dam) with central clay core for upper and lower reservoirs with a live storage of 13 million cum each, twin water conductor, an underground power house (157 m long, 22.5 m width, 48.7 m height) to accommodate four reversible pump turbines (vertical Francis, rated head 177m, maximum power discharge : 150 cum/sec) of 225 MW each, an underground transformer (280MVA of Four nos. 16.5kv/400kv) cavern (119 m long, 17 m width, 17 m height), an access tunnel to power house and 400 KV gas insulated substation linked through a cable tunnel. Two 400 KV double circuit transmission lines connecting Durgapur Sub-station and Arambagh Sub-station with the project has been developed to transmit and receive power.

Table A2.6: Salient Features of Purulia PSP Project (4 x 225 MW)

1.	**PSP Name**	**Purulia PSP**	11	**Upper Reservoir**	Existing
2	**Status**	Operational		Full Reservoir Level (FRL) (m)	516
3	**Type**	On-River (Kistobazar Nalla)		Max Height of Dam above deepest Foundation (m)	71
4	**State**	West Bengal		Live Storage (Mcum)	13
5	**District**	Puruilia	12	**Lower Resservoir**	Existing
6	**Nearest Railhead**	Barabhum		Full Reservoir Level (FRL) (m)	337
7	**Nearest Airport**	Ranchi		Minimum Draw Down Level (MDDL) (m)	300
8	**Coordinates**	Latitude: 23°11'49"N		Live Storage (Mcum	13
		Longitude: 86°05'55"E	13	**Powerhouse**	
9	**Pressure Shaft**			Capacity of each Unit (MW)	4 x 225
	Number	2		Head generation (m)	177
	Diameter (m)	7.7- 7.3		Turbine	Francis
10	**Tail Race**		14	**Annual Energy (MU)**	-
	Diameter (m)	8.7 to 5.6	15	**Estimated Cost (Rs. Crores)**	-

Source: CEA (2023a)

The Purulia PSP may operate in four different modes: synchronous condenser, generation, pumping, and line charging (up to 400kV bus). 16.5 kV is the generation voltage. Up till March 31, 2016, the total project expenditure (including IDC) was Rs 2,475.86 Cr, of which Rs 2,272.41Cr came from JICA finance and Rs 126.231Cr came from the State. The first 900 MW pumped storage project in India to operate successfully is the Purulia PSP. The primary project work began in May 2002 and was supposed to be finished by December 31, 2007, but on December 17, 2007, it was finished earlier than expected. The cost of the Purulia PSP Project was also decreased. The project cost was lowered to Rs 2,500 crores from the original estimate of Rs 2,952 crores. The Purulia PSP outperforms the design figure of 74% with an overall plant efficiency of 77.8%. [134].

7. Tehri St II PSP Project (500 MW)

133 https://en.wikipedia.org/wiki/Purulia_Pumped_Storage_Power_Station
134 https://www.wbsedcl.in/irj/go/km/docs/internet/new_website

Three parts make up the Tehri Hydropower Complex (2,400 MW): (i) Tehri Dam Project Stage-I (4x250=1,000 MW), (ii) Tehri Stage-II (4x250=1,000 MW) PSP the Koteshwar Dam Project (4x100=400 MW) and (iii). To utilize the water resources of the Bhagirathi river in its lower reaches prior to its confluence with the Alaknanda river, the Tehri Hydropower Complex is being created. The multifunctional Tehri Project Stage-I was put into service in 2006–07 and consists of a 260.5 m high rockfill dam and an underground power house with four 250 MW units each. The Koteshwar Dam Project (4x100 MW) is situated 22 km downstream of Tehri Dam (Stage I) and features a concrete gravity dam that is 97.5 meters high [135].

Table A 2.10: Salient Features of Tehri St. II Project (4 x 250 MW)

	Feature	Description			Feature	Description
1	**Name of PSP**	Tehri St II		**6**	**Upper Reservoir (Existing)**	Tehri Dam
2	**Present Status**	Operating			Full Reservoir Level (FRL) (m)	830
3	**Location and Access**				Minimum Draw Down Level (MDDL) (m)	740
	State	Uttrakhand			Length of the Dam at the top(m)	592
	District	Tehri			Height of Dam (above RBL) (m)	260.5
	River	Bhagirathi			Live Storage (Mcum)	2,615
	Nearest Railhead	Rishikesh			Gross Storage (Mcum)	3,540
	Nearest Airport	Dehradun		7	**Lower Reservoir (Existing)**	Koteshwar Dam
	Coordinates	Latitude: 30°22'41"N			Full Reservoir Level (FRL) (m)	612.5
		Longitude: 78°28'41"E			Minimum Draw Down Level (m)	598.5
4	**Penstock**				Height of Dam (above RBL) (m)	35
	Number	4			Live Storage (Mcum)	88.9
	Length	1,514		8	**Powerhouse**	Underground
	Diameter (m)	6			Installed Capacity (MW)	4 x 250
5	**Tail Race Tunnel**				Design Head (m)	188
	Number	2			Turbine	Reversible Vertical Francis
	Length (m)	2256.85		9	**Annual Energy (MU)**	1,268
	Diameter (m)	9		10	**Energy(MU) for Pumping**	1,712

(Source; CEA (2023a;Oct. 2025); https://thdc.co.in/en/content/tehri-pumped-storage-plant)

Tehri PSP is currently operating and have a peak power output of 500 MW. The PSP plant will use the reservoirs created by the Koteshwar Dam and the Tehri Dam St-I as its upper and lower reservoirs, respectively. There are four 250 MW reversible pump turbine units in the project. The Bhagirathi River's left bank will be home to the subterranean power plant. Reversible turbine/pump units will work in between the upper and lower reservoirs, which will have a 90-meter head difference. The project is of the closed loop type, and the PSP will function by recycling water between the two reservoirs. After completion of Tehri St II PSP an increment in generation capacity of 1,000 MW will be available for the northern Region. Thus, an annual generation of 2,475 million units will be available. For the operation of reversable pumping units, the energy requirement during off-peak will be about 3,104 MU. Once the Tehri PSP is fully functional, the Tehri Hydropower complex will become a major peaking station with an total installed capacity of 2,400 MW.

135 https://cea.nic.in/wp-content/uploads/hpm/ 2022/06/T_Report_ Nov21_MT.pdf) This was put into service in 2011–12

In July 2006, the Indian Government approved the PSP project, which had a debt-to-equity ratio of 70:30 and a project cost of Rs. 1,657.60 Cr, including IDC of Rs. 81.64 Cr at the December 5 pricing level. PL was granted in November 11 after the cost was later revised with estimates of Rs. 2,978.86 on April 10. On 31.7.2021, RCE-II of Rs. 4,825.60 Cr. (including IDC & FC of Rs 1,089.80 Cr.) at February 2019 Pl. was authorized. Lastly, the CEA has approved the revised cost estimates (RCE-II) for June 2023 PL [136].

8. Pinnapuram

(b) PSP plants not operating in pumping mode

1. Kadana PSP Project (240 MW)

The Kadana PSP project is situated in Gujarat State's Mahisagar District Panchmahals on the banks of the Mahi River. The project was commissioned in 1990 and is now in operation. Gujarat State Electricity Corporation Ltd. (GSECL) is in charge of carrying out the project. At latitude 23°18'30"N and longitude 73°49'45"E, the project's top dam site is situated on the Mahi River. The lower dam site is situated on the same river at latitude 23°15'46.6"N and longitude 73°42'5.8"E. The closest airport is at Ahemdabad/Vadodara, and the closest train station is in Godhara. Upper Dam/Reservoir (existing) is constructed across Mahi River with dam Height of 35.98 m. The project has a live storage of 42,500 Mc ft between a Full Reservoir Level (FRL) of 127.70 m and Minimum Draw down Level (MDDL) of 114 m. Lower Reservoir (Existing Dolatpura Weir) : Lower Reservoir (Dolatpura Weir) is constructed across Mahisagar River with dam height of 10.2 m. The project has a live storage of 1,502.6 Mc ft between a Full Reservoir Level (FRL) of 85.4 m and Minimum Draw down Level (MDDL) of 79.54 m (CEA, 2023a).

Table A2.7: Salient Features of Kadana PSP Project (240 MW)

1.	**PSP Name**	**Kadana PSP**	11	**Upper Reservoir**	Existing
2	**Status**	Not Operating in Pumping mode		Full Reservoir Level (FRL) (m)	127.7
3	**Type**	On-River (Mahi)		Max Height of Dam above deepest Foundation (m)	35.98
4	**State**	Gujarat		Live Storage ((McFt)	42500
5	**District**	Mahisagar	12	**Lower Resservoir**	Existing
6	**Nearest Railhead**	Godhara		Full Reservoir Level (FRL) (m)	85.4
7	**Nearest Airport**	Ahmedabad/Vadodara		Minimum Draw Down Level (MDDL) (m)	79.54
8	**Coordinates**	Latitude: 23°18’30’’N		Live Storage (McFt)	1502.6
		Longitude: 73°49'45"E	13	**Powerhouse**	
9	**Pressure Shaft**			Capacity of each Unit (MW)	4 x 60
	Number	4		Head generation (m)	43.50
	Diameter (m)	6		Turbine	Deriaz Kaplan
10	**Estimated Cost (Rs. Crores) (Price Level)**	310	14	**Annual Energy (MU)**	131.33

136 https://thdc.co.in/en/content/tehri-pumped-storage-plant

Source: CEA (2023a)

Water is transported to the powerhouse via four 6-meter-diameter pressure shafts and penstocks. The PSP project has a 48.20 m head and 240 MW of installed capacity overall. In a 90% reliable year, the project produces 337.03 MU of energy annually. The Tail Race Tunnel transports the water from the powerhouse to the river. In a 90% reliable year, four reversible pump/turbine units with an installed capacity of 60 MW each produce 337.03 MU of energy annually. It was suggested that the turbines would run at a rated speed of 142.86 r.p.m., with an average gross head of 43.5 m and a rated discharge of 168.7 cumecs.

Issues and problems in running existing Kadana PSP projects in Pumping mode

Each turbine/pump unit would need 65 MW of power when in pumping mode, with a rated discharge of 126.2 cumecs for 47 m head. Two 60 MW turbine/pump units were put into service in 1990, and two further units were put into service in 1998. While the machines ran in generating mode till 2004, a trial for pump mode operation was conducted during 2004–05. Furthermore, the machines' vibration issue prevented them from being used in pumping mode later on. Regarding this, the project authorities contacted CKD Blanksko (OEM) and presented their proposal for fixing the issue. However, because CKD Blanksko's offer to fix the machines was more expensive, GSECL and its management decided to employ their own internal knowledge to fix the issue (CEA, 2023a).

Initially, unit number three was regarded as the test unit for reviving Kadana PSP's Pump Mode Operation. Corrections such as replacing both bearings and aligning and centering the turbine shaft were necessary to fix the issue. In addition, Unit No. 3's stop log gates were taken down. Additionally, Unit No. 3's protection testing was finished and confirmed to be adequate. The unit operated correctly, according to the vibration analysis done in generating mode by an ex-BHEL specialist. Additionally, authorization from the irrigation department is required for reversible pumping mode. GSECL asked the Central Government to grant a fund of Rs. 450 crores through a program such as PSDF, etc. Similar corrections will be made for the Kadana PSP's reming units when unit 3 has operated successfully in pumping mode (CEA, 2023; CEA, 2023a).

Furthermore, GSECL has given IIT, Roorkee, the task of reviving the Pump Mode Operation of Kadana HEP. The RLA study of the civil structures and the CFD research are being planned based on the draft feasibility study report. In addition, a preliminary discussion with the OEM was held to discuss options for replacing full units while keeping the current civil infrastructure. The consulting services tender for a turbine that has been modified to operate in reversible mode is now open. The project site has already been visited by OEMs like VOITH, Andritz, and others, and NHPC is anticipated to do the same (CEA, 2023).

2. Sardar Sarovar PSP Project (6 x 200 MW)

The Sardar Sarovar PSP project is situated in Gujarat's Nandod District, close to Navagam town. The Narmada River's water is used to generate electricity. A gross head of 116.6 m is used to generate power. SSNNL is in charge of carrying out the project (CEA, 2023a). In 2004–06, the Sardar Sarovar Hydro Electric Project came online. The project's River Bed Power

House features six reversible motor/generator and pump/turbine units, each with an installed capacity of 200 MW (1,200 MW) (CEA, 2023a).

The upper reservoir of Sardar Sarovar PSP project is located at latitude of 21°49'50.4"N and longitude of 73°44'49.4"E while lower reservoir is located at latitude of 21°53'00.6"N and longitude of 73°39'29.2"E. The Upper Reservoir is existent on Naarmada River for which the height of the dam is 120.68 m and it has a live storage of 5760 Mcum. The Minimum Drawdown Level (MDDL) is 110.64 meters, while the Full Reservoir Level (FRL) is 138.68 meters. The Lower Reservoir, which is now on the Narmada River, has a dam height of 19.75 meters, a live storage capacity of 32.98 million cubic meters, a Full Reservoir Level (FRL) of 31.57 meters, and a Minimum Drawdown Level (MDDL) of 26.71 meters. Additionally, the six penstocks that make up the suggested water conductor system have a diameter of 7.61 meters and varied lengths ranging from 198.40 to 205.30 meters. Six turbines with a combined installed capacity of 1,200 MW will be operated using a gross head of 116.6 m. To transport water from the powerhouse back into the river, a 296-meter-long tail race tunnel is available (CEA, 2023a).

Table A2.8: Salient Features of Sardar Sarovar PSP Project (240 MW)

1.	**PSP Name**	**Sardar Sarovar PSP**	10	**Upper Reservoir**	Existing Sardar Sarovar Dam
2	**Status**	Not Operating in Pumping mode		Full Reservoir Level (FRL) (m)	138.68
3	**Type**	On-River (narmada)		Max Height of Dam above deepest Foundation (m)	120.68
4	**State**	Gujarat		Live Storage ((cumec)	5760
5	**District**	Nandod	11	**Lower Resservoir**	Existing - Gurudeshwar Weir Dam existing
6	**Nearest Railhead**	Ekta Nagar		Full Reservoir Level (FRL) (m)	31.57
7	**Nearest Airport**	Vadodara		Height of Dam (m)	19.75
8	**Coordinates**	Latitude: 21°49'50.4"N		Live Storage (Mcums)	32.98
		Longitude: 73°44'49.4"E	12	**Powerhouse**	
9	**Pressure Shaft**			Capacity of each Unit (MW)	6 x 200
	Number	5		Head generation (m)	100
	Diameter (m)	7.61		Turbine	Francis vertical Reversible
	Length	198.40 to 205.30 (varying for each)	13	**Annual Energy (MU)**	-

Source: CEA (2023a)

Issues and Problem Faced in running existing Sardar Sarovar PSP in Pumping mode

Because the lower reservoir at Garudeshwar Weir was not operational and the necessary equipment was not installed, the project was not running in pumping mode. Furthermore, after consulting with the states of Gujarat, M.P., and Maharashtra, the Narmada Control Authority (NCA) must decide whether to run the project in pumping mode. At Garudeshwar weir, the lower reservoir is now operating. To operate the project in pumping mode, however, a few pieces of equipment are needed (CEA, 2024c).

To operate in pumping mode, the following equipment must be installed: (i) isolated phase bus ducts or 13/8 KV, 400 KV cables for each of the six units; (ii) phase reversal switches for each of the six units; and (iii) a static frequency converter for each of the six units. A sum of Rs. 294/- Cr. is needed for the River Bed Power House (RBPH) of the Sardar Sarovar PSP Project in order to operate the pumping mode of all six units with a 200 MW capacity each. The partner States should share or contribute this money. The affected State governments are working to arrive at an agreement for sharing the resulting costs.

A2.2 Current Status of PSP Projects under Construction

At present 6 PSP projects with total installed capacity of 7.97 GW are under construction [137]. Table A2.9 presents details about projects currently under construction.

Table A2.9 Details about projects currently under construction

S.No	Name of PSP	State	Units x Capacity (MW)	Total Capacity (MW)	PSP Type	Development stage	Promoter	Status
1	Tehri St.-II	Uttarakhand	4x250	1,000	On River	Under Construction	THDC	Under Construction (2 Units Commissioned total 500 MW)
2	Kundah (Stage I,II&III)	Tamil Nadu	4x125	500	On River	Under Construction	Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO	Under Construction Likely commissioning by 2025-26 (Dec 2025)
3	Upper Sileru	Andhra Pradesh	9 x 150	1,350	On River	Under Construction	Andhra Pradesh Power Generation Corporation Limited (APGENCO)	Under Construction Likely commissioning by 2028-29 (Feb 2029)
4	Sharavathy	Karnataka	8 x 250	2,000	On River	Under Construction	Karnataka Power Corporation Limited	Likely commissioning by Dec'29
5	Pinnapuram	Andhra Pradesh	4x240+2x 120	1,200	Off- River	Under Construction	Greenko Solar Energy Pvt. Ltd	Under Construction 7 units commissioned total 1440MW)
6	MP30 Gandhisagar	Madhya Pradesh	7x240 +2x120	1,920	Off- River	Under Construction	Greenko Energies Private Limited	Likely commsiioning by 2028-29 (June 28)

137 https://cea.nic.in/wp-content/uploads/hpi/2025/01/Status_of_Pumped_Storage_Development_in_India_3.pdf

S.No	Name of PSP	State	Units x Capacity (MW)	Total Capacity (MW)	PSP Type	Development stage	Promoter	Status
7	Bhivpuri	Maharashtra		1,000		Under Construction	Tata Power	Under Construction
8	Bhavali	Maharashtra		**1,500**		Under Construction	JSW	Under Construction
* One unit of Tehri PSP (250 MW) is likey to be commissioned in FY 24-25 and three units (750 MW) are likely in FY 2025-26								

(Source; CEA, 2025, status Feb.1st 2025)

2. Kundah Stage I, II and III PSP Project (4 x 125 MW)

The Kundah PSP project site is located near Silambu town in Tamil Nadu State's Nilgiris on the Kundah River. TANGEDCO is responsible for implementing the Kundah PSP. Four 125 MW units will be installed in an underground powerhouse to produce electricity using a gross head of 240 meters. The project will have a 500 MW installed capacity overall. In a 90% reliable year with 95% machine availability, the Kundah PSP project's total design energy is projected to be 1005 MU (CEA, 2023a).

Table A2.11: Salient Features Of Kundah St. I, II & III PSP Project (4 X 125 MW)

	Feature	Description		Feature	Description
1	**Name of PSP**	Kundah St. I, II & III	**6**	**Upper Reservoir (Existing)**	(Porthimund
2	**Present Status**	Active construction (76% completed)		Full Reservoir Level (FRL) (m)	830
3	**Location and Access**			Minimum Draw Down Level (MDDL) (m)	2220.46
	State	Tamil Nadu		Length of the Dam at the top(m)	369
	District	Nilgiris		Height of Dam (above RBL) (m)	56.39
	River	Kundah		Live Storage (Mcum)	20.10
	Nearest Railhead	Mettupalayam		Gross Storage (Mcum)	60.12
	Nearest Airport	Coimbatore	7	**Lower Reservoir (Existing)**	Emerald
	Coordinates	Latitude: 11°22'35.4"N		Full Reservoir Level (FRL) (m)	1985.80
		Longitude: 76°34'19.2"E		Minimum Draw Down Level (m)	1957.98
4	**Penstock**			Height of Dam (above RBL) (m)	65
	Number	2		Live Storage (Mcum)	130.84
	Length	425	8	**Powerhouse**	Underground
	Diameter (m)	5		Installed Capacity (MW)	4 x 125
5	**Tail Race Tunnel**			Design Head (m)	230
	Number	1		Turbine	Francis
	Length (m)	895	9	**Annual Energy (MU)**	1,005
	Diameter (m)	8.5	10	**Energy(MU) for Pumping**	1,712

(Source: CEA (2023a); WAPCOS (2015))

The proposed upper reservoir for Kundah PSP, the existing Porthimund reservoir, consists of a 56.39-meter-high dam with a 369-meter-long crest and a 20.1-million-cubic-meter live storage capacity. Similar to this, the current Emerald reservoir on the Kundah River, which is intended to serve as the lower reservoir for the Kundah PSP, has a 65-meter-tall dam that can store 130.84 million cubic meters of water. Two 8.5-meter-diameter HRTs measuring 1,267.5 meters in length and a 5-meter-diameter penstock are part of the planned Water Conductor

System, which is now being built. Water will be transported from the powerhouse to the Kundah River by an 895-meter tale race tunnel (WAPCOS, 2015; CEA, 2023a). The Kundah PSP project falls within Kaducupa Reserve Forest. In order to minimize the forest land acquisition, it is proposed to use the existing corridors to form 230 KV multi circuit towers for the new lines and the existing transmission lines from this project. The proposed transmission system is being developed to for evacuation of 500MW of power in generation mode and on the same time it will be used for the power drawl of 525 MW in pumping mode. Further, as such there will not be any interstate water dispute issues involved as no water diversion/ water consumption or damming up of water in Kundah PSP will take place (WAPCOS, 2015). The Kundah PSP is implemented by TANGEDCO (CEA, 2023a).

At present the construction of Kundah PSP project is in the advanced stages and the scheduled commissioning of the project is planned for 2025-26 (Dec 2025) (CEA, 2025; status Feb.1st 2025).

3. Upper Sileru PSP Project (9X150MW- 1,350 MW)

The Visakhapatnam district of Andhra Pradesh is home to the Upper Sileru PSP project location. APGENCO is working on the project.The project will use water from the Sileru River by harnessing a gross head of 108.51 meters. The powerhouse comprises nine 150 MW units with a 1,350 MW installed capacity. The Donkarayi reservoir from the Lower Sileru hydroelectric project will serve as the Lower Reservoir, and the Guntawada reservoir from the Upper Sileru I & II hydroelectric project will serve as Upper Reservoir. For the project, a Surface-style power house is being built. The project contains 102.56 Mcum of live storage. Three HRTs, each measuring 2,768 meters in length and 12 meters in diameter, and nine penstocks, each measuring 385 meters in length and 6 meters in diameter, make up the water conductor system, which transports water to the semi-underground powerhouse. The project will be run with a 91.73 m design head. Three tail race tunnels, each 2,465 meters long, return the water discharged from the power house to the river (CEA, 2023a).

Table A12: Salient Features Of Upper Sileru PSP Project (9 x 150 MW – 1,350 MW)

	Feature	**Description**			**Feature**	**Description**
1	**Name of PSP**	Upper Sileru		**6**	**Upper Reservoir (Existing)**	Guntawada
2	**Present Status**	Active construction (Initial stages)			Full Reservoir Level (FRL) (m)	414.5
3	**Location and Access**				Minimum Draw Down Level (MDDL) (m)	406.75
	State	Andhra Pradesh			Length of the Dam at the top(m)	765.53
	District	Visakhapatnam			Height of Dam (above RBL) (m)	19.81
	River	Sileru			Live Storage (Mcum)	102.56
	Nearest Railhead	Narsipatnam Road			Gross Storage (Mcum)	122.72
	Nearest Airport	Visakhapatnam		7	**Lower Reservoir (Existing)**	Emerald
	Coordinates	Latitude: 18°03'33"N			Full Reservoir Level (FRL) (m)	316.08
		Longitude: 82°02'15"E			Minimum Draw Down Level (m)	306.08
4	**Penstock**				Height of Dam (above RBL) (m)	58.52
	Number	9			Live Storage (Mcum)	375.84

	Length	385 (each)		8	**Powerhouse**	Semi - Underground
	Diameter (m)	6			Installed Capacity (MW)	9 x 150
5	**Head Race Tunnel**				Design Head (m)	91.7
	Number	2			Turbine	Vertical-Francis
	Length (m)	2768 m (each)		9	**Energy (MU) for pumping**	5105.14
	Diameter (m)	12		10	**Estimated Cost (Rs. Crores**	10,444 (2019-20 Price level)

Source: CEA (2023a)

The project is now in its early phases of construction, with a commissioning date proposed for February 29, 2028 (CEA, 2025; status Feb.1st 2025). Additionally, MoEF&CC has given the Project Environmental Clearance (EC) in accordance with the EAC's recommendation. According to the article [138], the government authorities requested that APGENCO officials draft a comprehensive action plan for its quicker implementation. APGENCO already invited prequalification bids by 11 September 2024 for the supply and construction on an EPC basis of the 1,350 MW Upper Sileru PSP project [139].

4. Pinnapuram off-River closed loop PSP (1,200 MW)

The Pinnapuram PSP project is going to be the first off-Stream closed loop standalone project in the country. It is an integrated project with solar (1,000 MW) and wind (550 MW) components. The Pinnapuram PSP Project is being developed by GSEP. This Project is standalone in nature and both the reservoirs are located away from all existing natural water systems and have no/negligible catchment area. Water will be lifted one time from existing Gorakallu Reservoir irrigation system and will be stored in the reservoirs to be constructed and used cyclically for energy storage and discharge. Evaporation losses, if any will be recouped periodically. This Project envisages non-consumptive re-utilization of 1TMC of water for recirculation among two proposed reservoirs [140].

Table A2.13: Salient Features Of Pinnapuram PSP Project (1,200 MW)

	Feature	Description			Feature	Description
1	PSP Project Name	**Pinnapuram**			Dead storage	0.22 TMC
2	Type	Off-River closed loop			Gross storage	1.42 TMC
3	Capacity	1,200 MW			Max. Height of embankment	33m
4	Location and approach			9	Penstock/ Pressure shaft	5nos.
	State	Andhra Pradesh			Length	760m (each)
	District	Kurnool			Diameter	7m
	Near Village	Pinnapuram		10	Powerhouse	Surface
	Co-ordinates	Lat. 1559; Long. 78.31			Dimentions;	L - 240.00m B - 24.00 m
	Nearest railhead	Kurnool				H - 58.00 m
	Nearest Airport	Hyderabad		11.	Turbine/ Pump	Francis type, vertical shaft
5	Storage capacity	9,600 MWH				reversible pump-turbine

138 https://www.thehindu.com/news/national/andhra-pradesh/environment-ministry-set-to-give-its-nod-to-upper-sileru-pumped-storage-hydropower-project/article68481191.ece
139 https://www.hydropower-dams.com/news/andhra-pradesh-power-generation-corporation-seeks-epc-contractor-for-1350-mw-upper-sileru-pumped-storage-project-india/
140 https://greenkogroup.com/ap01.php

	Feature	Description			Feature	Description
6	Peak operation duration	8 hrs,				5 X 200MW 2 X 100 MW
7	Upper Reservoir				Discharge turbine mode	162.85 cumecs
	Live storage	1.2 TMC			Rated head in turbine mode	119.27m
	Dead storage	0.17 TMC			Pump capacity	244 MW
	Gross storage	1.37 TMC			Pump Discharge	178.42 cumecs
	Max. Height of embankment	35 m			Three (3) phase, alternating current synchronous, generator motor	5
	RCC intake structure height	45m				
8	Lower Reservoir					
	Live storage	1.2 TMC			Total Project Cost with IDC	Rs. 5468.02 Cr

Source: *https://forestsclearance.nic.in/writereaddata/Addinfo/0_0_8112512301201Annexure-K-FR-PIREP.pdf.pdf*

At present the construction of the project is in the advanced stages (80% of physical progress) and the scheduled commissioning of the project is planned for 2025-26 (July'25) (CEA, 2024e; CEA, 2025; Status Feb. 1st 2025). Further, 8 draft tubes have been installed and pressure testing of spiral cases was also completed in December 2023. With the foundational water conducting systems in place, the main installation of the turbine-generator for Unit 1 was undertaken. In January 2024, the stator assembly and turbine shaft were finished. The installation of the main unit is complete, and commissioning is underway. At the same time, all other units are being completed. According to this article, "Andritz makes more progress on Pinnapuram-psp,"

5. **Sharavati PSP project (8 x 250 MW)**

The Sharavathi PSP project (on River) is under construction in Karnataka state. The project is being developed by Karnataka Power Corporation Limited. The scheduled commissioning of this project is planned for Dec. 2029 (CEA, 2025; Status Feb. 1st 2025).

The project has faced opposition due to potential environmental damage, including forest loss and habitat fragmentation, and concerns over the impacts on the Sharavathi Lion-Tailed Macaque Sanctuary. With its dependable solution for balancing grid stability and meeting peak power demands, the Sharavathi Hydro Pump Storage Plant is set to play a significant role in the State's energy landscape. The facility, which has a sizable 2,000 MW capacity, would effectively store and produce power by utilizing the Sharavathi river system [141].

6. MP30 Gandhisagar PSP (7x240 +2x120 = 1,920 MW)

The MP30 Gandhisagar PSP is off – River type PSP and is under construction in Madhya Pradesh state. The project is being developed by Greenko Energies Private Limited. The scheduled commissioning of the project is planned for 2028-29 (June 28) (CEA, 2025; Status Feb. 1st 2025). The project is expected to utilize the existing Gandhi Sagar reservoir as the lower reservoir and a new upper reservoir to be constructed

References for Annexure-2

141 https://www.thehindu.com/news/national/karnataka/cea-gives-nod-for-dpr-of-sharavathi-pumped-storage-project/article68478899.ece

CEA (2023a) Reassessment of on river pumped storage hydroelectric potential in India. Pp. 528 https://cea.nic.in/wp-content/uploads/hp___i/2023/08/Pumped_Storage_On_River_Final_compressed.pdf accessed on 15.2.2024 (Ref.137)

CEA (2023) PUMPED STORAGE POTENTIAL IN THE COUNTRY - State-wise List of ON River Pumped Storage Projects (Status as on 31.5.2023) (https://cea.nic.in/wp-content/uploads/hpi/2023/05/Pumped_storage_potential_in_the_country.pdf) (Ref.144)

CEA (Central Electricity Authority) (2024e). Capacity addition plan of PSPs till 2031-32 (As on Sept..2024) (https://cea.nic.in/pumped-storage-plants/?lang=en). accessed on 10.9.2024

https://tatapower100.tatapower.com/locationpop/bhira.html

https://www.power-technology.com/data-insights/power-plant-profile-srisailam-lbph-psp-india/

https://www.power-technology.com/marketdata/ghatghar-psp-lower-india/

https://www2.jica.go.jp/en/evaluation/pdf/2012_ID-P53_4_f.pdf

https://en.wikipedia.org/wiki/Purulia_Pumped_Storage_Power_Station

https://www.wbsedcl.in/irj/go/km/docs/internet/new_website/PPSP.html

https://cea.nic.in/wp-content/uploads/hpm/ 2022/06/T_Report_ Nov21_MT.pdf

https://thdc.co.in/en/content/tehri-pumped-storage-plant

https://www.thehindu.com/news/national/andhra-pradesh/environment-ministry-set-to-give-its-nod-to-upper-sileru-pumped-storage-hydropower-project/article68481191.ece

https://greenkogroup.com/ap01.php

https://forestsclearance.nic.in/writereaddata/Addinfo/0_0_8112512301201Annexure-K-FR-PIREP.pdf.pdf

https://www.tndindia.com/andritz-makes-more-progress-on-pinnapuram-psp/

Loucks, D. P. (1992). Water Resources Systems Models: Their Role in Planning. Journal of Water Resources Planning and Management, 118(3), pp. 214 – 223.

Sivakumar, N., Das, D., Padhy, N. P., Senthil Kumar, A. R., & Bisoyi, N. (2013). Status of pumped hydro-storage schemes and its future in India. Renewable and Sustainable Energy Reviews, 19, 208–213.

Sivakumar, N., Das, D., Padhy, N.P., Senthil kumar, A.R. (2020). Deriving operating rules for mixed pumped storage plant: Kadamparai - A Case Study. J. Indian Water Resour. Soc., 40 (1&2): 1 -14

WAPCOS (2015) Kundah pumped storage hydro electric project, Nilgiris District / Tamil Nadu (https://environmentclearance.nic.in/DownloadPfdFile.aspx?FileName=yYkyC54jnWIz/Fw3h9olkiSwXvHY7CQEgFK6qV3F/yeSLGu17iorlWWQOchB5i26870GGoxvgqs9Ixk)

Wurbs, R. A. (1993) Reservoir-system simulation and optimization models. Journal of Water Resources Planning and Management, 119(4), pp. 455-472. https://doi.org/10.1061/(ASCE)0733- 9496(1993)119:4(455).

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ANNEXURE-3(A): State Wise Status of PSP Sites On River Under Operation and Various Stages of Development

S.No	Name of PSP	Latitude	Longitude	State	District	Total Capacity (MW)	Upper Reservoir	Lower Reservoir	Development stage	Promoter	Status
1	Majra	32.2123	75.6390	Himachal Pradesh	Kangra	700	Sarhyali Khad	Govind Sagar	Yet to be Allotted	BBMB	
2	Renukaji (Renuka)	30.6167	77.0500	Himachal Pradesh	Sirmaur	1630	Jogar ka Khala	Dadahu Storage	Preliminary Report Prepared	HPPCL (Himachal Pradesh Power Corporation Ltd.)	
3	Tehri	30.3750	78.4300	Uttrakhand	Tehri Garhwal	1000	Bhagirathi river	Bhagirathi river	In Operation	THDC	• Likely Commissioning - 2025-26 (Nov'25) • Out of total four units two units of Tehri PSP(250 MW x 2=500MW) has been commissioned during June & July2025
4	Ichari	30.6136	77.7911	Uttrakhand	Dehradun	600	newly proposed upper reservoir on the eastern side of Ichari reservoir	existing Ichari Dam	Proposal under Scrutiny	UJVN Ltd	CEA via letter dated 28.07.2025 requested CWC to confirm whether the proposal for Ichari can be taken up by UJVN
5	Ghatghar Stage-II	19.6088	78.9625	Maharashtra	Ahmednagar	125	Pravara river	Shahi Nalla	PFR Prepared in March-21	WRD, Maharashtra	Use of both reservoirs of Ghatghar PSP St.I
6	Malshej Ghat	19.1968	72.9787	Maharashtra	Ahmednagar/ Thane	700	Kalu river		Yet to be Allotted	THDCIL	Implementation agreement yet to be signed with Govt. of Maharashtra. DPR Prepared in May-2010

S.No	Name of PSP	Latitude	Longitude	State	District	Total Capacity (MW)	Upper Reservoir	Lower Reservoir	Development stage	Promoter	Status
7	Mutkhel	19.5260	73.7510	Maharashtra	Ahmednagar	110	Pravara		PFR Prepared in May-15	WRD, Maharashtra	
8	Warasgaon	18.3123	73.4691	Maharashtra	Pune/Raigad	1200	Mose river	Kal river	Balance	WRD, Maharashtra	• No progress on S&I acitivities from more than 6 months
9	Bhira	18.4550	73.3900	Maharashtra	Raigad	150	Mulla & Neela		In Operation	Tata Power	
10	Ghatgar	19.2830	73.7000	Maharashtra	Thana	250	Pravara		In Operation	Mahagenco	
11	Kengadi	19.1200	72.8900	Maharashtra	Thane	1550	Kengadi river	Bhatsa river	Yet to be Allotted	NHPC	
12	Jalond	19.1250	73.3750	Maharashtra	Thane	2400	Mula river	Jalond river	Yet to be Allotted	NHPC	
13	Amba	18.5300	73.5000	Maharashtra	Pune	800	Lonauli Lake	Amba river	Yet to be Allotted	NTPC	
14	Jalvara	17.7900	73.8300	Maharashtra	Ratnagiri/Belgaum	2220	Hajatar river	Jalvara river	Yet to be Allotted	SJVNL	
15	Koyna Left Bank	17.3960	73.745	Maharashtra	Satara	80	Koyna	Koyna	Balance	WRD, Maharashtra	• Project stalled since July, 2015. The current expenditure on the project has already reached to almost original administrative approved cost level. The proposal for execution with various options (By WRD/ Through BOT/ By MSPGCL in collaboration with WRD) is under process.Project is likely to be commissioned 4 years after restart of works

S.No	Name of PSP	Latitude	Longitude	State	District	Total Capacity (MW)	Upper Reservoir	Lower Reservoir	Development stage	Promoter	Status
16	Varandhghat	17.4832	73.8432	Maharashtra	Pune	800	Welvandi River	Kharak River	Preliminary Investigation Report prepared in Dec 16	WRD, Maharashtra	
17	Panshet	18.3400	73.4520	Maharashtra	Satara	1600	Mose River	Kal River	Preliminary Investigation Report Prepared	WRD, Maharashtra	
18	Nive	18.4880	73.4170	Maharashtra	Pune	1200	Kundalika River	Kundalika River	PFR Prepared in August-2015	WRD, Maharashtra	
19	Kodali	18.7890	74.1730	Maharashtra	Kolhapur	220	Kodali River	Kharal River	PFR Prepared in April-2014	WRD, Maharashtra	
20	Atvan	18.6800	73.3960	Maharashtra	Pune/raigad	500	pawana	uttara	PFR Prepared	WRD, Maharashtra	
21	Koyna St-VI	17.3910	73.8260	Maharashtra	Satara	400	Koyna	Koyna	Yet to be Allotted	WRD, Maharashtra	
22	Kadana	23.2900	73.8400	Gujarat	Panchmahal	240	Mahi	Mahi	In Operation	GSECL	Not working in Pumping mode
23	Sardar Sarover	22.8000	72.5800	Gujarat	Baharuch	1200	Narmada	Narmada	In Operation	SSNNL	Not working in Pumping mode
24	Indira Sagar-Omkareshwar	0.0000	0.0000	Madhya Pradesh	Khandwa	640	ISP Reservoirr	Omkareshwar reservior	Under Examination	NHDC ltd	
25	Chikni	23.4880	82.9740	Chattisgarh	Surajpur	325			TOR Granted	Chikni Energy Private Limited	• Proposal not yet received in CEA Date of grant of TOR-07.08.2023,
26	Kharauli	23.4840	82.9890	Chattisgarh	Surajpur	500			TOR Granted	Kharauli Energy Private Limited	• Proposal not yet received in CEA •Date of grant of TOR-10.09.2023,
27	Srisailam LBPH	16.0730	78.8700	Telangana	Karnool	900	Krishna		In operation	TSGENCO	

S.No	Name of PSP	Latitude	Longitude	State	District	Total Capacity (MW)	Upper Reservoir	Lower Reservoir	Development stage	Promoter	Status
28	Nagarjunasagar	16.5920	79.4900	Telangana	Nalgonda	705.6	Krishna river	Krishna river	In operation	TSGENCO	
29	Upper Sileru	18.0590	82.0370	Andhra Pradesh	Vishakhapatnam	1350	Guntawada reservoir	Donkarayi reservoir	Under Construction	APGENCO	•Likely commissioning by 2028- 29(Feb'29)
30	Kurukutti	18.6140	83.0450	Andhra Pradesh	Vizianagaram	1200	Minor nallah draining into Boduru Gedda river	Boduru Gedda river	Balance	NREDCAP & AGEL	Cancelled via G.O. Ms. No. 55 dated 28.07.2025
31	Karrivalasa	18.6360	83.0500	Andhra Pradesh	Vizianagaram	1000	Minor nallah draining into Boduru Gedda river	Boduru Gedda river	Balance	NREDCAP & AGEL	Cancelled via G.O. Ms. No. 55 dated 28.07.2026
32	Yerravaram PSP	17.6440	83.0060	Andhra Pradesh	Vishakhapatnam	1200	Nallah/Stream flowing into the Thandava reservoir,	Nallah/Stream flowing into the Thandava reservoir,	Balance	Shirdi Sai Electricals Ltd.	•Project held up- Drilling activity will be commenced upon resolving local issues
33	Sillahalla St.-I	11.3150	76.6490	Tamilnadu	Nilgiri	1000	Sillahalla		Balance	TANGEDCO	•Pre-DPR Chapters returned after there is no progress in the S&I activities by the developer
34	Kundah Pumped Storage (Stage I,II &III)	11.3770	76.5720	Tamilnadu	Nilgiri	500	Bhawani		Under Construction	TANGEDCO	• Likely commissioning by2025-27 (Apr'26) • 3 units (375 MW) likely during 2025-26, 1 unit (125 MW) likely during 2026-27.
35	Kadamparai	11.0170	76.9600	Tamilnadu	Coimbatore	400	Kadamparai river		In Operation	TANGEDCO	
36	Kodayar	8.5050	77.3110	Tamilnadu	Kanyakumari	500	Kodayar reservoir existing	PWD's Pechiparai reservoir-	Balance	TANGEDCO	•Pre-DPR Chapters returned after there is no progress in the S&I activities by the developer

S.No	Name of PSP	Latitude	Longitude	State	District	Total Capacity (MW)	Upper Reservoir	Lower Reservoir	Development stage	Promoter	Status
37	Sandynalla	11.4440	76.6520	Tamilnadu	Nilgiris	1200	Kundah	Kundah	Yet to be Allotted	NTPC	
38	Upper Bhavani	11.2300	76.5230	Tamilnadu	Nilgiris	1000	Upper Bhavani	Avalanche Emerald	Under S & I	NTECL	• Target date of DPR preparation- 04/26 •Date of MOA- 11.03.2024
39	Sigur	11.5910	76.7080	Tamilnadu	Nilgiris	800	Sigur	Sigur	Yet to be Allotted	NTPC	
40	Manalar	9.6380	77.3460	Tamilnadu	Theni	1200	Existing Manalar Reservoir	Proposed	Feasibility report prepared	TANGED CO along with Tractbel Pvt Ltd	
41	Chattar	8.4640	77.3760	Tamilnadu	kanyakumari	1100	Chattar Nallah	Kodayar	PFR Prepared	TANGED CO along with TATA Consultancy energy	
42	Karayar	8.6017	77.3114	Tamilnadu	Tirunelveli District	1000	Manpidi Ar	Thamirabarani	PFR Prepared	TANGED CO along with TATA Consultancy energy	
43	Aliyar	10.4370	77.0130	Tamilnadu	Coimbatore	700	Aliyar River		PFR Prepared	PFR prepared by TANGED CO	
44	Palar-Porathalar	10.3140	77.4530	Tamilnadu	Dindigul	1100	Poranthalar	Palar & Poranthalar	PFR Prepared	TANGED CO along with TATA Consultancy energy	
45	Athur	10.3040	77.7540	Tamilnadu	Dindigul	300	Kodaganar	Kodaganar	PFR Prepared	TANGED CO along with TATA Consultancy energy	

S.No	Name of PSP	Latitude	Longitude	State	District	Total Capacity (MW)	Upper Reservoir	Lower Reservoir	Development stage	Promoter	Status
46	Manjalar	10.2340	77.6510	Tamilnadu	Theni	500	Iruttar River	Manjalar	PFR Prepared	TANGEDCO along with TATA Consultancy energy	
47	Mettur	11.7830	77.6170	Tamilnadu	Erode	1000	Palar	Periya Pallam	PFR Prepared	TANGEDCO along with TATA Consultancy energy	
48	Varahi	13.7130	75.0020	Karnataka	Dakshina Kannada	1500	Varahi		Govt. of Karnataka allotted to KPCL	Govt. of Karnataka allotted to KPCL	Existing Varahi pick-up Dam as upstream reservoir. Lower reservoir to be constructed.
49	Sharavathy	14.2500	74.6750	Karnataka	Shivamonga	2000	Talakalale Reservoir-existing	Gerusappa Reservoir – existing	Under Construction	KPCL	Likely commissioning by 2029-30 (Dec'29)
50	Idukki	9.8030	76.8860	Kerala	Idukki	600	Periyar/cheruthoni/Killi Valli Thodu		Yet to be Allotted	Indicated by MoP to THDCIL	Existing Idukki reservoir.
51	Pallivasal	10.0630	77.0620	Kerala	Idukki	600	Mudirapuzha		Yet to be Allotted	Indicated by MoP to THDCIL	Existing Palliavsal reservoir
52	Lugupahar	23.7710	85.7250	Jharkhand	Bokaro	1500	Kairo Jharna Nala	across Bokaro River	Under S & I	DVC	• DVC letter dated 17.11.23 infromed that S&I activity on stalled since 10.09.23 due to local resistance at site
53	Kulbera	23.2570	86.0260	West Bengal	Purulia	800	Rupai Nala	Kulbera Nala	Yet to be Allotted	DVC	
54	Bandhu	23.2330	86.1560	West Bengal	Purulia	900	Bandhu Nala	Bandhu Nala	PFR under preparation	WBSEDCL	
55	Panchet Hill	23.6300	86.7640	West Bengal	Purulia	1000	Panchet Reservoir	Panchet Reservoir	Yet to be Allotted	DVC	
56	Purulia	23.3320	86.3700	West Bengal	Purulia	900	Kisto Bazar Nalla		In Operation	WBSEDCL	

S.No	Name of PSP	Latitude	Longitude	State	District	Total Capacity (MW)	Upper Reservoir	Lower Reservoir	Development stage	Promoter	Status
57	Turga PSS	23.2130	86.0720	West Bengal	Purulia	1000	Turga Nala		DPR Concurred by CEA	WBSEDCL	
58	Kathlajal	23.1740	86.1530	West Bengal	Purulia	900	Kathlajal Nala		Yet to be Allotted	WBSEDCL	
59	Balimela	18.2170	82.0830	Odisha	Malkangiri	500	Balimela existing reservoir	to be constructed on Kharika Johra	Under S & I	OHPCL	Project under S&I not in CEA
60	Panyor	27.4390	93.7050	Arunachal Pradesh	Lower Subansiri	660	Pit Nalah	Panyor / Ranganadi	Yet to be Allotted	NEEPCO	
61	Kopili	25.5290	92.6330	Assam	Dima Hasao	320	Khandong	Umrong	Yet to be Allotted	NEEPCO	
62	Leiva Lui	23.8710	93.2800	Mizoram	Aizawl	1500	Pharsih river	Leiva Lui river	Yet to be Allotted	NEEPCO	
63	Tuiphai Lui	23.0840	93.0390	Mizoram	Aizawl	1650	Tuiphai Lui river	Tuikual Lui river	Yet to be Allotted	NEEPCO	
64	Nghasih	22.9290	92.7730	Mizoram	Lunglai	400	Khawiva Lui river	Nghasih Lui river	Yet to be Allotted	NEEPCO	
65	Daizo Lui	22.7730	92.9640	Mizoram	Lunglai	2000	Koladyne river	Daizolui river	Yet to be Allotted	NEEPCO	

(Source: CEA, 2025, Status Oct. 2025 https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf)

Annexure 3 (B): State Wise Status of PSP Sites Off - Stream Under Operation and Various Stages of Development

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
1	Dhaulasidh (Sadda)	180	31.81	76.44	Himachal pradesh	Hamirpur	at Sadda (in a Depression)	Dhaulasidh HEP Reservoir (for both the alternatives)	Open	Yet to be Allotted	Yet to be allotted by the State for development	SJVNL	PFR Prepared
2	Koldam PSP-I &II	2400	31.38	76.87	Himachal pradesh		to be constructed (off Stream)	Koldam reservoir	Open	Yet to be Allotted	Yet to be allotted by the State for development	NTPC	PFR Prepared
3	Lehri	850	31.40	76.46	Himachal pradesh	Bilaspur		Bhakra reservoir		Yet to be Allotted	Yet to be allotted by the State for development	BBMB	
4	Raipur/Dobar Uparla	1500	31.45	76.43	Himachal pradesh	Una	To be constructed	Bhakra reservoir		Yet to be Allotted	Yet to be allotted by the State for development	BBMB	PFR Prepared
5	Sukhpura Off-Stream	2560	24.89	75.53	Rajasthan	Chittorgarh	Off -stream	Off -stream	Closed	Under S & I	Under S&I	Greenko	Project under S&I not in CEA
6	Shahpur	1800	25.19	77.18	Rajasthan	Baran	Off Stream	Off Stream,	Closed	Under S & I	Under S&I	Greenko	• Offstream closed loop, UR &LR - off stream • Target date of preparation of DPR-09/25
7	Sirohi	1200	24.99	72.96	Rajasthan	Sirohi	Off Stream	off stream	Closed	Under S & I	Under S&I	JSW Energy	
8	Rana Pratap Sagar	1200	24.85	75.69	Rajasthan	Chittorgarh			Closed	Under S & I	Under S&I	Semaliya Energy Private Limited	
9	Semaliya-II	1200	25.07	75.12	Rajasthan	Chittorgarh			Closed		TOR Granted		

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
10	Brahmani	600	25.05	75.12	Rajasthan	Chittorgarh	Offstream	Offstream	Closed	Under S & I	Under S&I	ACME Urja Two Private Ltd.	
11	Sirohi	640	24.99	72.96	Rajasthan	Sirohi			Closed		TOR Granted	Sasa Stone Private limited	
12	Balotra	1800	25.83	72.24	Rajasthan	Barmer			Closed		TOR Granted	Adani Green Energy Limited	
13	Kadambari	1560	24.77	73.08	Rajasthan	Pali & Sirohi			Closed		TOR Granted	Avaada Aqua Batteries Private Limited	
14	Maneri bhali	400	30.74	78.53	Uttarakhand				Closed		Proposal Under Scrutiny	UJVN Ltd	
15	Kandhaura	1680	24.48	83.13	Uttar Pradesh	Sonbhadra	Off Stream	Off Stream	Closed	DPR Concurred by CEA	Concurred and yet to be taken up for construction	JSW Energy	
16	Musakhand	600	24.98	83.22	Uttar Pradesh	Chandauli	Off Stream	Off Stream	Closed	Under S & I	Under S&I	ACME Urja Two Private Ltd.	
17	UP01	3660	24.53	83.31	Uttar Pradesh	Sonbhadra	Off Stream	Off Stream	Closed	Under S & I	Under S&I	Greenko	
18	Shoma	2400	24.54	83.37	Uttar Pradesh	Sonbhadra	Off Stream	Off Stream	Closed	Under S & I	Under S&I	Torrent Power	
19	Sonbhadra	1200	24.55	83.19	Uttar Pradesh				Closed		TOR Granted	Sri Siddharth Infratech & Services (I) Privated Limited	
20	Sashnai	1760	24.52	83.18	Uttar Pradesh				Closed		TOR Granted	Torrent Power limited	
21	Astha UP	640	24.86	82.11	Uttar Pradesh				Closed		TOR Granted	Astha Green Energy Ventures	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
												India Private Limited	
22	Panaura	1500	24.32	83.08	Uttar Pradesh	Sonbhadra	Off Stream	Off Stream	Closed	Under S & I	Under S&I	Adani Green Energy Limited	
23	Jhariya	1620	24.43	83.33	Uttar Pradesh	Sonbhadra	Off Stream	Off Stream	Closed	Under S & I	Under S&I	Jhariya anant urja	
24	Chichlik	1560	24.54	83.44	Uttar Pradesh	Sonbhadra	Off Stream	Off Stream	Closed	Under S & I	Under S&I	Avaada	
25	Kalu Patti	1000	25.14	82.56	Uttar Pradesh	Mirzapur	Off Stream	Off Stream	Closed	Under S & I	Under S&I	Renew Hydro	
26	MP30 Gandhi Sagar	1920	24.52	75.52	Madhya Pradesh	Neemach	Off Stream	Chambal	Open	Under Constructio n	Under Construction	Greenko MP01 IREP Pvt Ltd	
27	Tekwa-2	800	22.40	75.80	Madhya Pradesh	Khargone	Off Stream	Off Stream	Closed			NHDC	
28	Satpura-2	1000	22.40	78.82	Madhya Pradesh	Chhindwara			Closed	Yet to be Allotted	Yet to be allotted by the State for development	NHPC	
29	Panari	1800	24.91	80.49	Madhya Pradesh	Satna			Open		TOR Granted	Sri Siddharth Infratech & Services (I) Privated Limited	
30	Astha MP	1200	22.37	75.70	Madhya Pradesh	Khargone					TOR Granted	Astha Green Energy Ventures India Private Limited	
31	MP Pumped Storage Project	600	24.91	80.49	Madhya Pradesh	Panna					TOR Granted	Rithwik Projects Private Limited	
32	Rewa	600	24.82	81.86	Madhya Pradesh	Rewa					TOR Granted	Sasa Stone Private Limited	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
33	Jankhai	1500	0.00	0.00	Madhya Pradesh	Rewa			Closed		TOR Granted	GSC PSP Madhya Pvt Ltd	
34	Kundi	600	17.11	73.69	Maharashtra	Ratnagiri	Varna river	Nibera Vahal river	Open	Yet to be Allotted	Yet to be allotted by the State for development	NTPC	
35	Pane	1500	18.28	73.48	Maharashtra	Raigad	Off Stream	connected to a small stream which joins the downstream Kal river	open	DPR Concurred by CEA	Concurred and yet to be taken up for construction	JSW Energy	
36	Tarali	1500	17.51	73.89	Maharashtra	Satara	Off Stream	existing Tarali reservoir	open	Under S & I	Under S&I	Adani Green Energy Limited	
37	Malshej Ghat Bhorande	1500	19.20	72.98	Maharashtra	Pune & Thane	on Minor nallah draining into Kukadi river	on Minor nallah draining Into Kalu rive	Closed	Under S & I	Under S&I	Adani Green Energy Limited	
38	Aruna	1950	16.71	74.17	Maharashtra	Kolhapur	Kumbli river	Aruna river		Yet to be Allotted	Yet to be allotted by the State for development	THDCIL	
39	Humbarli Birmani	1000	17.41	73.74	Maharashtra	Satara/ Ratnagiri	minor nallah flowing to koyna river basin	On intial reaches of a nallah flowing to suk river		Yet to be Allotted	Yet to be allotted by the State for development	THDC	
40	Shirwata	1800	18.84	73.45	Maharashtra	Pune	offstream	existing Shirawata reservoir	open	DPR Concurred by CEA	Concurred and yet to be taken up for construction	TATA Power	
41	Bhivpuri	1000	18.94	73.49	Maharashtra	Raigad	existing Thokerwadi reservoir	offstream	open	Under Constructio n	Under Construction	TATA Power	
42	Warasgaon Warangi	1500	18.31	73.46	Maharashtra	Pune-Raigad	on minor nallah draining into Ambi river	on minor nallah draining into Kal river	open	Under S & I	Under S&I		

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
43	Patgaon	2100	16.11	73.92	Maharashtra	Sindhudurg and Kolhapur	existing Patgaon reservoir	to be constructed on tributary of Karli river			Balance	Adani Green Energy Limited	
44	Koyna Nivakane	2700	17.48	73.84	Maharashtra	Satara	minor rivulet draining into Kera River/ Koyna river	minor rivulet draining into Kera River/ Koyna river	Closed	Under S & I	Under S&I		
45	Nayagaon	2000	20.46	75.36	Maharashtra	Chhatrapati Sambhajinagar	offstream	minor nallah draining into Hivra River	Closed	Under S & I	Under S&I	Greenko	
46	Mhaismal	800	20.08	75.21	Maharashtra	Aurangabad					TOR Granted	Greenko Energy Private Limited	
47	KOLHAPUR	1200	16.01	74.10	Maharashtra	Kolhapur					TOR Granted	Rithwik Projects Privated Limited	
48	Maval (Saidongar-2)	1200	18.90	73.45	Maharashtra	Pune and Raigarh	offstream	Initial filling by rainfall yield of self-catchment of the lower reservoir only	open	Under S & I	Under S&I	Torrent power	
49	karjat (Saidongar-1)	3000	18.90	73.45	Maharashtra	Raigad	offstream	Initial filling by rainfall yield of self-catchment of the lower reservoir only	open	Under S & I	Under S&I	Torrent power	
50	Kamod	2000	21.09	73.94	Maharashtra	Nandubar	offstream	offstream	closed	Under S & I	Under S&I	Megha engineering	
51	Pawana Falyan	2400	18.81	73.66	Maharashtra	Pune - Raigad	offstream	offstream	Closed	Under S & I	Under S&I	Avaada	
52	Ghosla	2000	20.50	75.45	Maharashtra	Aurangabad	offstream	offstream	Closed	Under S & I	Under S&I	Megha engineering	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
53	Kalamb Thakurwadi	1000	18.62	73.34	Maharashtra	Raigad			Closed			Renew Solar Power Pvt Ltd	
54	Savitri	2400	17.97	73.67	Maharashtra	Satara-Raigad	upper dam proposed across Koyna River	lower dam proposed across Savitri River	Open	Under S & I	Under S&I	NHPC	
55	Ambegaon	500	19.11	73.73	Maharashtra	Ambegaon			Open		TOR Granted	Renew Hydro Power Pvt Ltd.	
56	Bhavali	1500	19.61	73.60	Maharashtra	Nashik/thane	downstream of Bhavali Dam	Ulhas river	Open	Under Constructio n	Under Construction		
57	Kumbhe	1100	0.00	0.00	Maharashtra	Raigad	Upper Dam is under construction by Water Resource Department, Govt. of	offstream	Open	Under S & I	Under S&I	NTPC	
58	Adnadi	1500	0.00	0.00	Maharashtra	Amravati	offstream	offstream	Closed		Balance	Adani Hydro Energy Pvt LTd	
59	Kalu	1800	0.00	0.00	Maharashtra	Pune & Thane	offstream	offstream	Closed	Under S & I	Under S&I	NHPC	
60	Dangari	1400	23.17	83.58	Chhattisgarh	Jashpur	Bichri Nala	Goer river		Yet to be Allotted	Yet to be allotted by the State for development	CSPGCL	
61	Rouni	2100	23.05	83.62	Chhattisgarh	Jashpur	Off Stream	on river IB , tributori of Mahanadi	Open	Under S & I	Under S&I	CSPGCL	
62	CHH-09	1200	22.81	83.11	Chhattisgarh	Surguja			Closed		TOR Granted	Sterlite Grid 36 Limited	
63	Gandhwani	1200	23.50	82.93	Chhattisgarh	Surguja			Closed		TOR Granted	Gandhwani Energy Private Limited	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
64	Bilaspur	1000	21.47	81.14	Chhattisgarh	Bilaspur	Off Stream	Off Stream	Closed	Under S & I	Under S&I	DVC	
65	Sikaser	1200	20.52	82.32	Chhattisgarh	Gariyaband	Off Stream	Sikaser Dam	Open	Under S & I	Under S&I	CSPGCL	
66	Chirec	75	23.48	82.81	Chhattisgarh	Surajpur			Closed		Submitted	Venika Green Power Private Limited	
67	Parsapani	1000	22.50	82.11	Chhattisgarh	Bilaspur	off Stream	Off Stream	Closed		TOR Granted	Hunduja Renewable Energy limited	
68	Hasdeo Bango	800	22.63	82.45	Chhattisgarh	Korba	Off Stream	Existing Hasdeo Bango Reservoir on Hasdeo River	Open	Under S & I	Under S&I	CSPGCL	
69	Kotpali	1800	23.50	83.70	Chhattisgarh	Balrampur			Closed		TOR Granted	Chhattisgarh State Power Generation Company Limited	
70	Ukai	1600	21.35	73.61	Gujarat	Tapi	Off Stream	Off Stream	Closed	Under S & I	Under S&I	Greenko	
71	Pindval	1000	20.48	73.34	Gujarat	Valsad					TOR Granted	Torrent Power	
72	Tokarpada	1300	20.34	73.39	Gujarat	Valsad					TOR Granted	Torrent Power	
73	Serula	960	19.58	73.59	Gujarat	Tapi	Off Stream	Off Stream	Closed	Under S & I	Under S&I	GSECL	
74	Juni Kayaliwel	300	19.58	73.59	Gujarat	Tapi	Off Stream	Off Stream	Closed	Under S & I	Under S&I	GSECL	
75	Amalpada	300	21.27	73.69	Gujarat	Tapi	Off Stream	off Stream	Closed	Under S & I	Under S&I	GSECL	
76	Juni Bavli	450	21.28	73.61	Gujarat	Tapi	Off Stream	existing Ukai Reservoir	open	Under S & I	Under S&I	GSECL	
77	Satkashi	330	21.33	73.68	Gujarat	Tapi	Off Stream	Off Stream	Closed	Under S & I	Under S&I	GSECL	
78	Dharoi	500	24.00	72.85	Gujarat	Banaskantha	Off Stream	Dharoi Reservoir	Open	Under S & I	Under S&I	GSECL	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
79	Sukhi	500	22.43	73.88	Gujarat				Open		Proposal Accepted and Referred to EAC	GSECL	
80	Dharampur	1500	20.54	73.17	Gujarat				Open		Proposal returned in present form	Adani Green Energy Limited	
81	Motaraypura	1000		0.00	Gujarat	Narmada	new upper reservoir	existing Karjan Dam	Open	Under S & I	Under S&I	GSECL	
82	Pinnapuram	1680	15.59	78.31	Andhra Pradesh	Kurnool	Near Gorakallu reservoir in Pannapuram Village	In Pannapuram Village	Closed	In operation	Under Construction (1 nos. of units) / In Operation (7 nos. of units)	Greenko AP01 IREP Private Limited	
83	Gandikota	1000	14.83	78.23	Andhra Pradesh	Kadapa	Off Stream	Gandikota reservoir on Penna River	Open	Under Constructio n	Under Construction	Adani Green Energy Limited	
84	Chitravathi	500	14.57	77.94	Andhra Pradesh	Ananthapuramu	Off Stream	Chitravathi	Open	Under Constructio n	Under Active Construction	Adani Renewable Energy Forty-Two Limited	
85	Somasila	900	14.63	79.18	Andhra Pradesh	Kadapa	Off Stream	Off Stream,	Open		Balance	Shirdi Sai Electricals Ltd.	
86	Owk	800	15.16	78.07	Andhra Pradesh	Kurnool	Off Stream	Owk reservoir on Penna River	Open		Balance	RVR Project Pvt Ltd	
87	Paidipalem East	1200	14.71	78.22	Andhra Pradesh	YSR	new proposed Off Stream	new proposed draws water Paidipalem Balancing reservoir	Closed		Balance	Indosol Solar Power Pvt. Ltd.	
88	Singanamala	800	14.85	77.70	Andhra Pradesh	Ananthapuramu	Off Stream	Off Stream	Closed		Balance	NREDCAP & AGEL	
89	Paidipalem North	1000	14.73	78.19	Andhra Pradesh	YSR	new proposed Off Stream	new proposed draws water Paidipalem	Closed		Balance	Indosol Solar Power Pvt. Ltd.	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
								Balancing reservoir					
90	Veeraballi Off-Stream	1800	14.22	78.87	Andhra Pradesh	Annamayya	Off Stream	Off Stream	Closed		Balance	Astha Green Energy Ventures India Private Limited	
91	Vempalli	1500	14.37	78.47	Andhra Pradesh	YSR Kadapa	Off Stream	Off Stream	Closed	Under S & I	Under S&I	JSW Energy	
92	Gujjili	2400	18.35	83.07	Andhra Pradesh	Alluri Sitharama Raju	Off Stream	Off Stream	Closed	Under S & I	Under S&I	NECL	
93	Raiwada	900	18.02	82.98	Andhra Pradesh	Anakapalle	on a tabletop hill across a minor rivulet draining into a nallah	across Sarada river	Open	Under S & I	Under S&I	Adani Green Energy Limited	
94	Chittamvalasa	1800	18.21	82.89	Andhra Pradesh	Alluri Sitarama Raju	Off Stream	Off Stream	Closed	Under S & I	Under S&I	NECL	
95	Yaganti	1000	15.34	78.13	Andhra Pradesh	Nandyal	Minor rivulet	Minor rivulet	Closed		Balance	APGENCO	
96	Kamalapadu	950	15.03	77.39	Andhra Pradesh	Ananthapuramu	Off Stream	Off Stream	Closed	Under S & I	Under S&I	APGENCO	
97	Aravetipalli	1320	14.74	79.54	Andhra Pradesh	YSR	Off Stream	Off Stream	Closed		Balance	APGENCO	
98	Rayavaram	1500	13.96	79.05	Andhra Pradesh	Annamayya	On minor Stream	On minor Stream	Closed	Under S & I	Under S&I	APGENCO & ONGC	
99	Gadikota	1200	14.16	78.95	Andhra Pradesh	Annamayya	Off Stream	Off Stream	Closed	Under S & I	Under S&I	APGENCO	
100	Pedakota	1800	17.28	80.88	Andhra Pradesh	Alluri Seetharama Raju	on minor stream draining into the Sarada River	on minor stream draining into the Sarada River	Closed	Under S & I	Under S&I	Adani Green Energy Limited	
101	Rajupalem	350	14.23	79.24	Andhra Pradesh	YSR Kadapa	offstream	existing Racheruvu dam/reservoir	open		Under Examination in MOEF	NREDCAP	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
102	Yadaballi	1200	14.21	78.89	Andhra Pradesh	Annamayya	offstream	offstream	closed		Proposal returned in present form	NREDCAP	
103	Koppolu	2400	0.00	0.00	Andhra Pradesh	YSR Kadapa			Open	Under Constructio n			
104	Velimalai	1100	8.14	77.32	Tamil Nadu	Kanyakumari	Palayar / Pazhayar	Valliyar			PFR Prepared	TANGEDC O along with TATA Consultancy energy	
105	Sillahalla Stage-II	1000	11.28	75.80	Tamil Nadu	Nilgiris & Coimbtore	New Reservoir	Bhavani	Open	Yet to be Allotted	Yet to be allotted by the State for development	NTPC	
106	Greenko TN01	1200	12.83	78.84	Tamil Nadu	Tirupathar			Closed		TOR Granted	Greenko Energy Private Limited	
107	Arunachalam	900	12.02	78.71	Tamil Nadu	Dharamapuri and tiruvannamalai			Closed		TOR Granted	Volthills Private Limited	
108	Tiruvannamalai	2000	12.55	79.02	Tamil Nadu	Tiruvannamalai			Closed		TOR Granted	Eco Leap Technologies India private limited	
109	Greenko TN -11	1000	11.66	78.15	Tamil Nadu	Salem			closed		TOR Granted	Greenko Energie private limited	
110	Saundatti	1600	15.86	75.01	Karnataka	Belgavi	Off the river	Malaprabha	closed	Under Constructio n	Under Construction	Greenko KA01 IREP Private Limited	
111	Netravathy Stage I	1500	13.02	76.08	Karnataka	Hasan	Kaginahare	Kemphole	Open	Yet to be Allotted	Yet to be allotted by the State for	NTPC	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
112	Narihalla	300	15.10	76.61	Karnataka	Bellary	proposed on minor rivulet draining into	Narihalla Reservoir existing on Narihalla River	Open	Under S & I	Under S&&I	JSW Energy	
113	Shanti Sagar	270	14.12	75.87	Karnataka	Davanagere					TOR Granted	Cerulean Energy Solutions Privated Limited	
114	Vijayanagar	130	15.16	76.63	Karnataka	Bellary			Closed		TOR Granted	JSW Renewable Energy (Vijayanagar) Limited	
115	Sankanoor	300	16.96	77.09	Karnataka	Kalaburagi			Closed		TOR Granted	Cerulean Energy Solutions Privated Limited	
116	Ippagudem	3960	18.28	80.67	Telangana	Mulugu			Closed		TOR Granted	Greenko energie Private Limited	
117	Ranapur	1200	19.21	78.33	Telangana	Adilabad			Closed		TOR Granted	Sri Siddharth Infratech & Services (I) Private Limited	
118	Greenko TS01	750	19.57	78.33	Telangana	Adilabad			Closed		TOR Granted	Greenko Energies Private Limited	
119	Astha Telangana	600	18.57	78.52	Telangana	Nizamabad			Closed		TOR Granted	Astha Green Energy Ventures India Private Limited	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
120	Cerulean-II	640	19.44	79.44	Telangana	Komarambheem			Closed		TOR Granted	Cerulean Energy Solutions Privated Limited	
121	Upper Indravati	600	19.42	82.85	Odisha	Kalahandi			Open	DPR Concurred by CEA	Concurred and yet to be taken up for construction	OHPC	
122	Upper Kolab	600	18.89	82.56	Odisha	Koraput			Open	Under S & I	Under S&I	OHPC	
123	Greenko OD01	1200	19.44	82.91	Odisha	Kalahandi					TOR Granted	Greenko Energies Private Limited	
124	Ramial Left	1500	21.25	85.57	Odisha	Keonjhar					TOR Granted	Renew Solar Power Private Limited	
125	Tainsar	675	21.57	84.66	Odisha	Deogarh					TOR Granted	Jindal Renewable Power Private limited	
126	Masinta	1000	21.62	84.93	Odisha	Deogarh	Off Stream	Off Stream	Closed	Under S & I	Under S&I	NHPC	
127	Saurali	840	21.53	84.70	Odisha	Deogarh			Closed		MoU signed	Jindal Renewable Power Private limited	
128	Bihar New PSP-1	910	24.75	85.50	Bihar	Nawada			Closed			Sun Petrochemicals Pvt Ltd	
129	Bihar New PSP-2	920	24.75	85.50	Bihar	Nawada			Closed			Sun Petrochemicals Pvt Ltd	

S.N.	Name of PSP	Installed Capacity (MW)	Lat.	Long.	State	District	River		Loop	Status	Status	Developer	Remarks
							Upper Reservoir	Lower Reservoir					
130	Bihar New PSP-3	650	24.75	85.50	Bihar	Nawada			Closed			Sun Petrochemicals Pvt Ltd	
131	Longtarai	800	23.92	91.89	Tripura	Dhala	Off Stream	Off Stream	Closed	Under S & I	Under S&I	NHPC	
132	Greenko Assam-01	900	26.00	92.27	Assam	Karbi Anglong & Marigaon			Closed		TOR Granted	Greenko Energies Pvt. Ltd	

(Source: CEA, 2025, Status Oct. 2025 https://cea.nic.in/wp-content/uploads/pumpedstorage/2025/10/PSP_Potential.pdf)

ANNEXURE-3(C): TOTAL PSP SITES IN VARIOUS STATES IDENTIFIED, DEVELOPED, UNDER VARIOUS STAGES OF DEVELOPMENT OR DROPPED DUE TO VARIOUS REASONS

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
1	Aravetipalli	1320	14.739	79.539	Andhra Pradesh	YSR	APSPCL	Off River	Under Survey and Investigation						Aug_2024	CEA (2024c)(Ref_164)	Under Survey and Investigation
2	Chitravathi	500	14.574	77.935	Andhra Pradesh	Ananthapuramu	Adani Green Energy Limited	Off River open loop	Under Survey and Investigation	Granted	Oct_18_ 2021	EC: 28/08/2023 ; transfer of EC application submitted.	FC: not required	MOA- 29.06.2022	Mar_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132); EAC (27.3.2023) (Ref_138)	MOM 48th EAC June 26-27, 2023
3	Chittamvalasa	800	18.211	82.886	Andhra Pradesh	Alluri Sitarama Raju	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	Off River closed loop	Under Survey and Investigation	Granted	Sept_10 _2023				Aug_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 49th EAC July 24, 2023
4	Gadikota	1200	14.163	78.952	Andhra Pradesh	Annamayya	NREDCAP	Off River closed loop	Under Survey and Investigation	Granted	Jan_30_ 2024					MoEF&CC (2024) (Ref_132; Ref_145)	Under Survey and Investigation
5	Gandikota	1000	14.830	78.231	Andhra Pradesh	Kadapa	Adani Green Energy Limited	Off River open loop	Under Survey and Investigation	Granted	Jan_14_ 2022	EAC Discussed in (Oct 23), deferred for ADS:	In Progress	MOA- 29.06.2022	Mar_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 19th EAC Nov 15, 2021
6	Gujjili	1500	18.348	83.069	Andhra Pradesh	Alluri Sitharama Raju	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	Off River closed loop	Under Survey and Investigation	Granted	Aug_7_ 2023			MOA- 25.01.2022	Mar_2025	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM_48_EAC_ June_26_27_2023
7	Kamalapadu	950	15.026	77.385	Andhra Pradesh	Ananthapuramu	APGENCO	Off River	Under Survey and	Granted	Aug_7_ 2023			MOA- 23.08.2023	Aug_2024	CEA (2024c); MoEF&CC	Under Survey and Investigation

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								closed loop	Investigation							(2024) (Ref_164; Ref_132)	
8	Karrivalasa	1000	18.636	83.050	Andhra Pradesh	Vizianagaram	Adani Green Energy Limited	Off River open loop	Survey and Investigation Held up	Granted	Dec_16_2021		Interstate Disputed Land			MoEF&CC (2024) (Ref_132); CEA (2023b) (Ref_134)	MOM 18th EAC Oct 28, 2021
9	Kurukutti	1200	18.614	83.045	Andhra Pradesh	Vizianagaram	Adani Green Energy Limited	Off River open loop	Survey and Investigation Held up	Granted	Dec_16_2021		Interstate Disputed Land			MoEF&CC (2024) (Ref_132); CEA (2023b) (Ref_134)	MOM 18th EAC Oct 28, 2021
10	OWK Reservoir	800	15.160	78.068	Andhra Pradesh	Kurnool	Aurobindo Realty & Infrastructure Pvt. Ltd	Off River open loop	Under Survey and Investigation	Granted	Jan_4_2022			MOA-12.09.2022	Mar_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 19th EAC Nov 15, 2021
11	Paidipalem East	1200	14.705	78.222	Andhra Pradesh	YSR	Indosol Solar Power Pvt. Ltd	Off River closed loop	Under Survey and Investigation	Granted	April_17_2023		Delisted	MOA-12.09.2022	July_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 43rd EAC March 07, 2024
12	Paidipalem North	1000	14.732	78.186	Andhra Pradesh	YSR	Indosol Solar Power Pvt. Ltd	Off River closed loop	Under Survey and Investigation	Granted	April_17_2023		Delisted	MOA-12.09.2022	July_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 43rd EAC March 07, 2023
13	Pedakota	1800	17.28	80.88	Andhra Pradesh	Alluri Seetharama Raju	Adani Green Energy Ltd	Off-Stream Open Loop	Under Survey and Investigation					MOA-23.05.2022	Jun-25	CEA (2024c)	
14	Pinnapuram	1200	15.593	78.308	Andhra Pradesh	Kurnool	Greenko Solar Energy Pvt. Ltd	Off River closed loop	Under Costruction			EC: 14.07.2020	FC-I: 23.05.2020; FC-II: 24.05.2021			CEA (2023a) (Ref_137; Ref_144)	DPR Concurred on 20.04.2022 - Likely commsiioning by 2024-25 (Dec 24)
15	Raiwada	850	18.022	82.977	Andhra Pradesh	Anakapalli and Vizianagaram	Adani Green Energy Limited	Off River open loop	Under Survey and Investigation	Granted	Oct_25_2023		In Process	MOA-23.05.2022	Jan_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	Under Survey and Investigation

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16	Rajupalem	350	14.230	79.240	Andhra Pradesh	YSR Kadapa	NREDCAP	Off River open loop	Under Survey and Investigation						Aug_2024	(CEA (2023a) (Ref_144)	Under Survey and Investigation
17	Rayavaram	1500	13.956	79.054	Andhra Pradesh	Annamayya	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	Off River closed loop	Under Survey and Investigation	EAC found site not suitable	Jan_30_2024				June_2025	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 4th EAC November 24, 2023
18	Singanamala	800	14.853	77.695	Andhra Pradesh	Ananthapuramu	Aurobindo Realty & Infrastructure Pvt. Ltd.	Off River closed loop	Under Survey and Investigation	Granted	Feb_13_2023	Proposal submitted - Feb 24, EDS raised	In Progress	MOA-12.09.2022	Sept_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 38th EAC Dec 15, 2022
19	Somasila	900	14.634	79.178	Andhra Pradesh	Kadapa	Shirdi Sai Electricals Ltd.	Off River closed loop	Under Survey and Investigation	Granted	June_29_2022		In Progress	MOA-19.01.2023	Mar_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 27th EAC May 09, 2022
20	Tigaleru	800	15.190	78.090	Andhra Pradesh	Kurnool	NTPC	Off River open loop	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
21	Upper Sileru	1350	18.059	82.037	Andhra Pradesh	Visakhapatnam	Andhra Pradesh Power Generation Corporation Limited (APGENCO)	On River	Under Costruction	Granted	June_3_2019	EC proposal discussed in EAC in Feb 24 deferred to next meeting;	In Process			CEA (2023a) (Ref_137; Ref_144)	DPR Concurred by CEA
22	Veeraballi	1800	14.217	78.872	Andhra Pradesh	Annamayya	Astha Green Energy Ventures India PVT. LTD	Off River	Under Survey and Investigation	Granted	July_13_2020		In Progress	MOA-12.09.2022	Feb_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 32nd EAC May 15, 2020
23	Vempalli	1500	14.367	78.467	Andhra Pradesh	YSR	JSW Energy	Off River closed loop	Under Survey and	Granted	Aug_7_2023		In Process	MOA-25.01.2022	Mar_2025	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	Under Survey and Investigation

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									Investigation								
24	Yadaballi	1200	14.208	78.888	Andhra Pradesh	Annamayya	NREDCAP	Off River closed loop	Proposal under preparation	EAC found site not suitable						EAC MoEF&CC (18/12/2023) (Ref_139)	MOM 4th EAC November 24, 2023
25	Yaganti	1000	15.344	78.132	Andhra Pradesh	Nandyal	APGENCO	Off River closed loop	Under Survey and Investigation	Granted	Aug_7_ 2023			MOA-23.08.2023	Aug_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 48th EAC June 26-27, 2023
26	Yerravaram	1200	17.644	83.006	Andhra Pradesh	Vishakhapatnam	Shirdi Sai Electricals Ltd.	Off River	Survey and Investigation Held up	Granted	Jan_24_ 2022					MoEF&CC (2024) (Ref_132)	MOM 21st EAC Dec 23, 2021
27	Panyor	660	27.439	93.705	Arunachal Pradesh	Lower Subansiri	NEEPCO	On River	Yet to be allotted							CEA (2023) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
28	Kopili	320	25.529	92.633	Assam	Dima Haso	NEEPCO	On River	Yet to be allotted							CEA (2023) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
29	Hathidah & Durgawat	1600	24.674	83.729	Bihar	Kaimur	BHPC (through NHPC)	On River	Fall in restricted area								
30	Panchgotia	225	24.779	83.631	Bihar	Kaimur	BHPC (through NHPC)	On River	Fall in restricted area							CEA (2023a) (Ref_137)	Site fall in Wild Life Sanctuary
31	Sinafdar	345	24.830	86.610	Bihar	Kaimur	BHPC (through NHPC)	On River	Fall in restricted area							CEA (2023a) (Ref_137)	Site fall in Wild Life Sanctuary
32	Telharkund	400	24.831	83.522	Bihar	Kaimur	BHPC (through NHPC)	On River	Fall in restricted area							CEA (2023a) (Ref_137)	Site fall in Wild Life Sanctuary
33	CHH-09	1200	22.807	83.111	Chattisgarh	Surguja	Sterlite Grid 36 Limited	Off River closed loop	Proposal under preparation	Granted	Jan_222 _2024					MoEF&CC (2024) (Ref_132)	MOM 1st EAC October 17-18, 2023
34	Chikni	325	23.488	82.974	Chattisgarh	Surajpur	Chikini Energy	On River	Proposal under	Granted	Aug_7_ 2023					EAC (11.10.2022)	MOM 35th EAC Oct 11, 2022

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							Private Limited	open loop	preparation							MoEF&CC (Ref_136)	
35	CHIREC	75	23.479	82.810	Chattisgarh	Surajpur	Venika Green Power Private Limited	No Details available	EAC decided to defer the proposal.							MoEF&CC (2024) (Ref_132)	MOM 48th EAC June 26-27, 2023
36	Dangari	1400	23.170	83.580	Chattisgarh	Jashpur	CSPGCL	Off River	Yet to be allotted	proposal returned in present form by EAC	Feb_19_2024					MoEF&CC (2024) (Ref_132)	MOM 49th EAC July 24, 2023
37	Gandhwani	1200	23.504	82.929	Chattisgarh	Surguja	Gandhwani Energy Private Limited	Off River closed loop	Proposal under preparation	Granted	Feb_5_2024					MoEF&CC (2024) (Ref_132; Ref_145)	Proposal under preparation
38	Hasdeo Bango	1200	22.712	82.706	Chattisgarh	Korba	Chhattisgarh State Power Generation Company Limited	On River	Proposal under revision	Granted	Jan_10_2024					MoEF&CC (2024) (Ref_132; Ref_145)	Proposal under preparation
39	Kharauli	500	23.484	82.989	Chattisgarh	Surajpur	Kharauli Energy Private Limited	On River open loop	Proposal under preparation	Granted	Sept_10_2023					CEA (2023) (Ref_144) EAC MoEFCC (19/02/2024) (Ref_148)	Yet to be allotted by the State for development
40	Rauni	2100	23.050	83.620	Chattisgarh	Raigarh	CSPGCL	Off River	Yet to be allotted	Deferred for ADS - EAC	Feb_19_2024					CEA (2023) (Ref_144) EAC MoEFCC (19/02/2024) (Ref_148)	Yet to be allotted by the State for development
41	Kadana	240	23.290	73.840	Gujarat	Mahisagar	Gujarat State Electricity Corporation Ltd (GSECL	On River	Presently Not Operating in Pumping							Greenco Energies PFR (Ref_128.pdf)	Draft MOM 31st EAC March 05, 2020
42	Pindval	1000	20.476	73.340	Gujarat	Valsad	Torrent Power Limited	Off River	Proposal under preparation	Granted	Sept_23_2023					CEA (2023a) (Ref_137; Ref_144)	Operating

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43	Sardar Sarovar	1200	22.800	72.580	Gujarat	Nandod	Sardar Sarovar Narmada Nigam Limited	On River	Presently Not Operating in Pumping							CEA (2023a) (Ref_137; Ref_144)	Operating
44	Tokarpada	1300	20.343	73.386	Gujarat	Valsad	Torrent Power Limited	Off River	Proposal under preparation	Granted	Sept_23_2023					MoEF&CC (2024) (Ref_132; Ref_145)	Proposal under preparation
45	Ukai	2400	21.347	73.609	Gujarat	Tapi	Greenko Energies Private Limited	Off River	Proposal under preparation	Granted	Apr_13_2020					MoEF&CC (2024) (Ref_132; Ref_145)	Proposal under preparation
46	Chera Khad	500	31.540	76.960	Himachal Pradesh	Mandi & Shimla	SJVNL	On River	Yet to be allotted							CEA (2023a) (Ref_137)	CEA Report June 2023
47	Dhaulasidh (Sadda)	180	31.810	76.440	Himachal Pradesh	Hamirpur	SJVNL	Off River open loop	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	Preliminary Report Prepared
48	Dhurmu	1600	31.710	76.930	Himachal Pradesh	Mandi & Shimla	SJVNL	On River	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
49	Koldam PSP-I &II	2400	31.380	76.870	Himachal Pradesh	Bilaspur	NTPC	Off River open loop	PFR Prepared							CEA (2023) (Ref_144)	Yet to be allotted by the State for development
50	Lehri	850	31.400	76.460	Himachal Pradesh	Bilaspur	BBMB	Off River open loop	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
51	Majra	700	31.469	76.496	Himachal Pradesh	Kangra	Bhakra Beas Management Board (BBMB)	On River	Project considered by CEA for further study							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
52	Purthi & Sach Khas	190	32.900	76.460	Himachal Pradesh	Chamba	SJVNL	On River	Yet to be allotted							CEA (2023a) (Ref_144)	PFR Prepared
53	Raipur/Dobar Uparla	1500	31.450	76.430	Himachal Pradesh	Una	BBMB	Off River	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development

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								open loop									
54	Renukaji	1630	30.663	77.454	Himachal Pradesh	Sirmour	Himachal Pradesh Power Corporation Ltd (HPPCL)	On River	Preliminary Report Prepared							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
55	Matlimarg	1650	33.608	75.643	Jammu and Kashmir	Udhamnagar	NHPC	On Stream open loop	Project found not feasible by CEA							CEA (2023a) (Ref_137)	CEA Report June 2023
56	Boro	500	23.930	85.763	Jharkhand	Hazaribagh	DVC	On River	Project found not feasible							CEA (2023a) (Ref_137)	CEA - Unexploitable technically not feasible
57	Lugu Pahar	1500	23.771	85.725	Jharkhand	Bokaro	DVC	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
58	Hulagi	2200	13.184	75.641	Karnataka	Chikmanglur	Not Specified	On River	Unexploitaable site - MoEFCC restricted construction			No construction in Western Ghats - MoEFCC				CEA (2023a) (Ref_137)	Unexploitaable site - MoEFCC restricted construction
59	Kollur	900	13.912	74.862	Karnataka	Shimoga	Not Specified	On River	Unexploitaable site - MoEFCC restricted construction			No construction in Western Ghats - MoEFCC				CEA (2023a) (Ref_137)	Unexploitaable site - MoEFCC restricted construction
60	Minhole	2200	13.676	75.046	Karnataka	Shimoga	Not Specified	On River	Unexploitaable site - MoEFCC restricted construction			No construction in Western Ghats - MoEFCC				CEA (2023a) (Ref_137)	Unexploitaable site - MoEFCC restricted construction
61	Narihalla	300	15.104	76.607	Karnataka	Ballari	JSW Energy PSP Three Limited	Off River	Under Survey and	Granted	July_5_2023		In Process	MOA-28.11.2022	July_2024	CEA (2024c); MoEF&CC	Commissioned Dec_24

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								open loop	Investigation							(2024) (Ref_164; Ref_132)	
62	Netravathy Stage I	1500	13.020	76.080	Karnataka	Hasan	NTPC	Off River open loop	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
63	Sankanoor	300	16.958	77.086	Karnataka	Kalaburagi	Cerulean Energy Solutions Private Limited	Off River closed loop	Proposal under preparation	Granted	Aug_7_ 2023					MoEF&CC (2024) (Ref_132)	Proposal under preparation
64	Saundatti	1600	15.860	75.012	Karnataka	Belagavi	Greenko KA01 IREP Pvt. Ltd	Off River closed loop	Under Survey and Investigation	18.5.2018 amended 25.09.2018; transfer of EC proosal submitted on 28.11.23; ADS raised by MS		19.09.22 amended 24.03.2023	FC-I: 18.12.2018 , FC-II pending	MOA-27.02.19	Mar_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 3rd EAC Oct 29, 2020
65	Saundatti IREP	1260	15.856	75.005	Karnataka	Belagavi	Greenko Solar Energy Private Ltd.	Off River closed loop	Under Survey and Investigation						July_2023	Greenco (2018 (Ref_140); CEA (2024); MoEF&CC (2024) (Ref_125; Ref_132)	MOM 3rd EAC Oct 29, 2020
66	Shanti Sagar	270	14.120	75.873	Karnataka	Devanagere	Cerulean Energy Solutions Private Limited	Off River	Proposal under preparation	Granted	Jan_17_ 2020					MoEF&CC (2024) (Ref_132)	MOM 29th EAC December 05, 2019
67	Sharavathy	2000	14.250	74.675	Karnataka	Uttara Kannada	Karnataka Power Corporation Limited	On River	Under Survey and Investigation	Granted	Dec_14_ 2023		In Process	MoA- 07.12.2017	Mar_2024	CEA (2023a) (Ref_137; Ref_144)	Survey and Investigation Held up

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68	Sitanadi	2600	13.496	75.116	Karnataka	Shimoga	Not Specified	On River	Unexploitaable site - MoEFCC restricted construction			No construction in Western Ghats - MoEFCC				CEA (2023a) (Ref_137)	Unexploitaable site - MoEFCC restricted construction
69	Varahi	1500	13.713	75.002	Karnataka	Shivamogga & Udupi	KPCL	On River	Project considered by CEA for further study							CEA (2023a) (Ref_137)	CEA Report June 2023
70	Vijayanagar	130	15.159	76.634	Karnataka	Ballari	JSW Renewable Energy (Vijayanagar) Limited	Off River closed loop	Proposal concurred by state govt.	Granted	June_3_ 2022	EC: Recommended in Nov. 23 ; ADS raised.				MoEF&CC (2024) (Ref_132)	MOM 1st EAC October 17-18, 2023
71	Idukki	300	9.803	76.886	Kerala	Idukki	THDCIL	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
72	Kuttiyadi	900	11.551	75.925	Kerala	Kozhikode	KSEBL	On River	Unexploitaable site - MoEFCC restricted construction			No construction in Western Ghats - MoEFCC				CEA (2023a) (Ref_137)	Unexploitaable site - MoEFCC restricted construction
73	Pallivasal	600	10.063	77.062	Kerala	Idukki	THDCIL	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
74	Amba	800	18.690	73.408	Maharashtra	Pune	NTPC	On River	Yet to be allotted							CEA (2023a) (Ref_137)	CEA Report June 2023
75	Aruna	1950	16.710	74.170	Maharashtra	Kolhapur	THDCIL	Off River	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
76	Atvan	500	18.680	73.396	Maharashtra	Pune/Raigad	WRD, Maharashtra	On River	Preliminary Report/ PFR Prepared							CEA (2023a) (Ref_137; Ref_144)	PFR Prepared

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77	Baitarni	1800	17.600	73.697	Maharashtra	Satara	SJVNL	On River	Project not feasible/Fall in restricted area							CEA (2023a) (Ref_137; Ref_144)	Reservoirs fall within Koyna Wildlife Sanctuary
78	Bhavali	1500	19.609	73.596	Maharashtra	Nashik, Thane	JSW Energy PSP Two Limited	On River	Under Survey and Investigation	Granted	June_27_2022			MOA-14.09.2021	March_2024	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132)	MOM 20th EAC Dec 14, 2021
79	Bhira	150	18.455	73.390	Maharashtra	Raigad	Tata Power Company Limited (TPCL)	On River	Operating in Pumping Mode							CEA (2023a) (Ref_137; Ref_144)	Operating since 1951
80	Bhivpuri	1000	18.936	73.487	Maharashtra	Raigarh and Pune	The Tata Power Co. Ltd.	Off River open loop	Under Survey and Investigation	Amendment of TOR applied	Sept_23_2023		In Process	MOA-08.08.2023	June_2024	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132); MoEF&CC IA Division (01/04/2024) (Ref_142)	MOM 9th EAC March 20, 2024
81	Chikaldara	400	21.399	77.351	Maharashtra	Amravat	Not Specified	On River	Project not feasible/Fall in restricted area			Project site falls in Melghat Tiger Reserve forest				CEA (2023a) (Ref_137)	Unexploitaable site - It falls in buffer zone of Melghat Tiger Reserve
82	Chornai	2000	19.546	73.656	Maharashtra	Thane	SJVNL	On River	Project not feasible/Fall in restricted area							CEA (2023a) (Ref_137)	Reservoirs fall within Bheema Shankar Jyotirilinga Sanctuary
83	Ghatghar	250	19.283	73.700	Maharashtra	Thane	Maharashtra State Power Generation CO.LTD (MAHAGENCO)	On River	Operating in Pumping Mode							CEA (2023a) (Ref_137; Ref_144)	Operating

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84	Ghatghar Stage-II	125	19.542	73.667	Maharashtra	Ahmednagar/Thane	WRD, Maharashtra	On River	Preliminary Report/ PFR Prepared							CEA (2023a) (Ref_137; Ref_144)	Preliminary Report Prepared (March 2021)
85	Humbarli Birmani	1000	17.410	73.740	Maharashtra	Satara and Ratnagiri	THDCIL	Off River	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
86	Jalond	2400	19.440	73.721	Maharashtra	Thane	NHPC	On River	Yet to be allotted							CEA (2023a) (Ref_137)	CEA Report June 2023
87	Jalvara	2220	15.669	74.145	Maharashtra	Sindhudurg	SJVNL	On River	Yet to be allotted							CEA (2023a) (Ref_137: Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
88	Kalu	1150	19.200	72.980	Maharashtra	Thane	NHPC	On River	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
89	Kengadi	1550	19.684	73.458	Maharashtra	Thane	NHPC	On River	Yet to be allotted							CEA (2023a) (Ref_137)	CEA Report June 2023
90	Kengadi	1550	19.684	73.458	Maharashtra	Thane	NHPC	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
91	Kodali	220	18.789	74.173	Maharashtra	Kolhapur	WRD, Maharashtra	On River	Preliminary Report/ PFR Prepared							CEA (2023a) (Ref_137; Ref_144)	PFR Prepared in April-2014
92	Kolhapur	1200	16.013	74.102	Maharashtra	Kolhapur	Rithwik Projects Private Limited	Off River	Proposal under preparation	Granted	June_13 _2023					MoEF&CC (2024) (Ref_132); EAC (27.3.2023) (Ref_138)	MOM 44th EAC March 27-28, 2024
93	Kolmondapada	800	19.583	73.661	Maharashtra	Ahmednagar	SJVNL	On River	Project not feasible/Fall in restricted area							CEA (2023a) (Ref_137)	PSP fall in Wildlife Sanctuary
94	Koyna Left Bank	80	17.402	73.751	Maharashtra	Satara	WRD, Maharashtra	On River	Construction is held up							CEA (2023a) (Ref_137; Ref_144)	Construction is held up - Likely commissioning by 2027-28

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
95	Koyna Nivakane	2700	17.483	73.843	Maharashtra	Satara	Adani Green Energy Limited	Off River closed loop	Under Survey and Investigation	Granted	Aug_7_ 2023				June_2025	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132)	MOM 48th EAC June 26-27, 2023
96	Koyna Stage-VI	400	17.391	73.826	Maharashtra	Satara	WRD, Maharashtra	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
97	Kundi	600	17.110	73.690	Maharashtra	Ratnagiri	NTPC	Off River open loop	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
98	Madliwadi	900	17.010	73.340	Maharashtra	Ratnagiri	NTPC	Off River open loop	Yet to be allotted							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development
99	Malshej ghat Bhorande	1500	19.197	72.979	Maharashtra	Pune & Thane	Adani Green Energy Limited	Off River closed loop	Under Survey and Investigation	Amendment in TOR applied	Mar_24 _2023			MOA-28.06.2022	May_2024	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132)	MOM 39th EAC Dec 28, 2022
100	Mhaismal	800	20.080	75.207	Maharashtra	Aurangabad	Greenko Energies Private Limited	Off River	Proposal under preparation	Granted	Feb_28_ 2020					Greenco Energies PFR (Ref_129.pdf)	MOM 29th EAC December 05,
101	Mutkhel	110	19.523	73.769	Maharashtra	Ahmednagar	WRD, Maharashtra	On River	Preliminary Report/ PFR Prepared							CEA (2023a) (Ref_137; Ref_144)	Preliminary Report Prepared (March 2015)
102	Nayagaon	2000	20.455	75.361	Maharashtra	Aurangabad	Greenko Energies Private Limited	Off River closed loop	Under Survey and Investigation	Granted	April_13 _2020		In Progress	MOA-16.01.2023	June_2025	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132)	Draft MOM 31st EAC March 05, 2020
103	Nive	1200	18.488	73.417	Maharashtra	Pune/Raigad	WRD, Maharashtra	On River	Preliminary Report/ PFR Prepared							CEA (2023c) (Ref_137; Ref_144)	PFR Prepared in August-2015

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
104	Pane	1500	18.281	73.481	Maharashtra	Pune and Raigarh	JSW Energy PSP Seven Limited	Off River open loop	Under Survey and Investigation	Granted	Jan_30_ 2024		In Process	MOA- 29.09.2022	June_2024	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132)	Under Survey and Investigation
105	Panshet	1600	18.340	73.452	Maharashtra	Pune/Raigad	WRD, Maharashtra	On River	Preliminary Report/ PFR Prepared							CEA (2023a) (Ref_137; Ref_144)	Preliminary Investigation Report prepared (March 2017)
106	Patgaon	2100	16.113	73.919	Maharashtra	Sindhudurg	Adani Green Energy Limited	On River	Survey and Investigation Held up	Granted	Nov_9_ 2022			MOA- 28.06.2022	Dec_2023	MoEF&CC (2024) (Ref_132); CEA (2023a) (Ref_134)	MOM 33rd EAC Aug 29, 2022
107	Pinjal	700	19.845	73.591	Maharashtra	Thane	NHPC	On River	Project not feasible/Fall in restricted area							CEA (2023a) (Ref_137)	Low head high L/H ratio (CEA)
108	Saidongar-2	1200	18.900	73.447	Maharashtra	Raigad and Pune	Torrent Power Limited	Off River	Proposal under preparation	Granted	Sept_23 _2023					MoEF&CC (2024) (Ref_132)	MOM 48th EAC June 26-27, 2023
109	Saidongar-I	3000	18.900	73.447	Maharashtra	Raigad and Pune	Torrent Power Limited	Off River	Proposal under preparation	Granted	Sept_23 _2023					MoEF&CC (2024) (Ref_132)	MOM 48th EAC June 26-27, 2023
110	Savitri	1800	17.971	73.665	Maharashtra	Satara	NHPC	On River	Under Survey and Investigation							CEA (2024c) (Ref_125)	CEA status Report 28.2.2024
111	Shirawta	1800	18.841	73.454	Maharashtra	Pune	The Tata Power Co. Ltd.	Off River open loop	Under Survey and Investigation	Amendment of TOR applied	Sept_23 _2023 amendment of TOR applied		In Process			MoEF&CC (2024) (Ref_132); MoEF&CC IA Division (09/05/2024) (Ref_141)	EC/MOM/EAC/ 408274/4/2024
112	Shirwata	1800	18.811	73.457	Maharashtra	Pune	TATA power	Off River	Under Survey and	Amendment of	Sept_23 _2023		In Process	MOA- 08.08.2023	June_2024	CEA (2024c); MoEF&CC	CEA Status report (As on 29.2.2024);

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
								open loop	Investigation	TOR applied	(Applied)					(2024) (Ref_125; Ref_132)	MoEF&CC (2024)
113	Sidgarh	1500	19.160	73.578	Maharashtra	Thane	SJVNL	On River	Project not feasible/Fall in restricted area							CEA (2023a) (Ref_137)	Reservoirs fall within Bheema Shankar Jyotirilinga Sanctuary
114	Tarali	1500	17.508	73.889	Maharashtra	Satara	Adani Green Energy Limited	On River open loop	Under Survey and Investigation	Granted	Jan_3_2024			MOA-28.06.2022	April_2024	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132)	MOM 1st EAC October 17-18, 2023
115	Ulhas	1000	18.890	73.436	Maharashtra	Pune	NHPC	On River	Project not feasible/Fall in restricted area							CEA (2023c) (Ref_137)	CEA Report June 2023
116	Varandhghat	800	18.196	73.621	Maharashtra	Pune/Raigad	WRD, Maharashtra	On River	Preliminary Report/ PFR Prepared							CEA (2023a) (Ref_137; Ref_144)	Preliminary Investigation Report prepared (Dec 2016)
117	Warasgaon warangi	1500	18.306	73.463	Maharashtra	Pune and Raigad	Adani Green Energy Limited	Off River open loop	Under Survey and Investigation	Granted	Feb_13_2023			MOA-28.06.2022	June_2024	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132)	MOM 38th EAC Dec 15, 2022
118	Hengtam	500	24.029	93.576	Manipur	Churchandpur	NEEPCO	On River	Unexploitable at present							CEA (2023a) (Ref_137)	CEA - lesser head, higher dam in poor geology and less storage
119	Tuivai	1500	24.235	93.363	Manipur	Churchandpur	NEEPCO	On River	Unexploitable at present							CEA (2023a) (Ref_137)	CEA - Unexploitable at present
120	Daizo Lui	2000	22.773	92.964	Mizoram	Lunglai	SJVNL	On River	Yet to be allotted							CEA (2023a) (Ref_137)	CEA - lesser head, higher dam in poor geology and less storage
121	Khuai Lui	2100	23.931	92.670	Mizoram	Kolasib	Not Specified	On River	Project found not feasible							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
																	Status Report as on 31.5.2023
122	Khuailui	2100	23.931	93.670	Mizoram	Kolasib	NEEPCO	On River	Unexploitable at present							CEA (2023a) (Ref_137)	CEA Report June 2023
123	Leiva Lui	1500	23.871	93.280	Mizoram	Saitual	NEEPCO	On River	Yet to be allotted							CEA (2023a) (Ref_137)	CEA Report June 2023
124	Mat	1400	23.279	92.779	Mizoram	Serchhip	NEEPCO	On River	Unexploitable at present							CEA (2023a) (Ref_137)	CEA Report June 2023
125	Nghasih	400	22.929	92.773	Mizoram	Lunglai	NEEPCO	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
126	Pakwa	1000	23.888	92.449	Mizoram	Aizawl	NHPC	On River	Unexploitable at present							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
127	Pakwa	1000	23.890	92.450	Mizoram	Aizawl	Not Specified	On River	Unexploitable at present							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
128	Tuiphai Lui	1650	23.084	93.039	Mizoram	Aizawl	NEEPCO	On River	Yet to be allotted							CEA (2023a) (Ref_137)	Project found not feasible by CEA
129	TuithoLui	1050	23.627	93.341	Mizoram	Aizawl	NEEPCO	On River	Unexploitable at present							CEA (2023a) (Ref_137)	Unexploitable at present - CEA
130	Astha MP	1200	22.367	75.702	Madhya Pradesh	Khargone	Astha Green Energy Ventures India Private Limited	Off River open loop	Proposal under preparation	Granted	April_17_2023					MoEF&CC (2024) (Ref_132)	MOM 42nd EAC Feb 23, 2023
131	Binauda	2250	23.210	81.043	Madhya Pradesh	Mandla	Not Specified	On River	Unresolved issues			Unresolved issues of Forest Land, wild life clearance and coal mines				CEA (2023a) (Ref_137)	No development due to unresolved issues
132	Indira Sagar	640	22.285	76.472	Madhya Pradesh	Khandwa	NHDC	On River	Under Survey and Investigation					MOA-07.06.2023	June_2024	CEA (2024c) (Ref_125)	CEA - MOA-07.06.2023

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
133	Indira Sagar-Omkareshwar	525	22.285	76.472	Madhya Pradesh	Khandwa	NHDC	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
134	Kabra	1200	22.443	78.293	Madhya Pradesh	Hoshangabad	Not Specified	On River	Unresolved issues			Unresolved issues of Forest Land, wild life clearance and coal mines				CEA (2023a) (Ref_137)	No development due to unresolved issues
135	Mara	1100	23.876	82.443	Madhya Pradesh	Sidhi	Not Specified	On River	Unresolved issues			Unresolved issues of Forest Land, wild life clearance and coal mines				CEA (2023a) (Ref_137)	No development due to unresolved issues
136	MP 30 Gandhi Sagar	1920	24.519	75.516	Madhya Pradesh	Neemuch	Greenko Energies Private Limited	Off River open loop	Under Survey and Investigation	Granted	Feb_28_2020	EC: Grant 01-12- 2021; EC amendment Transfer : 13-02-2023	FC-II: 09.06.2023	MOA-13.10.2021	Mar_2024	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132)	MOM 4th EAC December 02, 2020
137	MP Pumped Storage Project	600	24.825	80.305	Madhya Pradesh	Panna	Rithwik Projects Private Limited	Off River	Proposal under preparation	Granted	June_13_2023					MoEF&CC (2024) (Ref_132)	MOM 44th EAC March 27-28, 2023
138	Panari	1800	24.911	80.486	Madhya Pradesh	Panna & Satna	Sri Siddharth Infratech & Services (I) Private Limited	Off River open loop	Proposal under preparation	Granted	March_13_2020					MoEF&CC (2024) (Ref_132); CEA (2023a) (Ref_134)	Draft MOM 31st EAC March 05, 2020
139	Rewa	600	24.821	81.855	Madhya Pradesh	Rewa	Sasa Stone Private Limited	Off River open loop	Proposal under preparation	Granted	June_13_2024					MoEF&CC (2024) (Ref_132); EAC (27.3.2023) (Ref_138)	MOM 44th EAC March 27-28, 2023
140	Satpura-2	1000	22.400	78.820	Madhya Pradesh	Chhindwar	NHPC	Off River closed loop	PFR Under Preparation							CEA (2023a) (Ref_144)	PFR Under Preparation
141	Tanbia	1600	22.175	78.375	Madhya Pradesh	Chindwara	Not Specified	On River	Unresolved issues			Unresolved issues of Forest Land, wild life				CEA (2023a) (Ref_144)	No development due to unresolved issues

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												clearance and coal mines					
142	Tekwa-2	800	22.400	75.800	Madhya Pradesh	Khargone	NHPC	Off River closed loop	PFR Under Preparation							CEA (2023a) (Ref_144)	PFR Under Preparation
143	Balimela	500	18.217	82.083	Odisha	Malkangiri	Odisha Hydro Power Corporation Limited	On River	Under Survey and Investigation	Granted	May_21_2020					MoEF&CC (2024) (Ref_132); EAC (2023) (Ref_126)	MOM_42_EAC_Feb_23_2023
144	Greenko OD01	1200	19.442	82.913	Odisha	Kalahandi	Greenko Energies Private Limited	Off River	Proposal under preparation	Granted	April_17_2023				Dec_2024	CEA (2024c); MoEF&CC (2024) (Ref_125; Ref_132)	MOM 29th EAC December 05, 2019
145	Greenko OD01	1200	19.442	82.913	Odisha	Kalahandi	Greenko Energies Private Limited	Off River closed loop	Proposal under preparation	Granted	April_17_2023					MoEF&CC (2024) (Ref_132)	MOM 1st EAC October 17-18, 2023
146	Jhalmara	2500	20.610	82.400	Odisha	Sambalpurand Raipur	Not Specified	On River	Project found not feasible						Dec_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 29th EAC December 05, 2019
147	Jharlama	2200	20.612	82.400	Odisha	Sambalpur	NHPC	On River	Yet to be allotted					MOA-29.07.2015	Mar_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132); EAC (27.3.2023) (Ref_138)	MOM 44th EAC March 27-28, 2023
148	Ramial Left	1500	21.253	85.566	Odisha	Keonjhar	Renew Solar Power Private Limited	Off River	Proposal under preparation	Granted	Jan_15_2024					MoEF&CC (2024) (Ref_132)	MOM 4th EAC November 24, 2023
149	Tainsar	675	21.569	84.659	Odisha	Deogarh	Jindal Renewable Power Private Limited	Off River open loop	Proposal under preparation	EAC found site not suitable	Jan_22_2024					CEA (2023a) (Ref_137)	CEA Report June 2023
150	Upper Indravati	600	19.422	82.851	Odisha	Kalahandi	Odisha Hydro Power Corporation Limited	Off River open loop	Under Survey and Investigation	Granted	Dec_14_2023					MoEF&CC (2024) (Ref_132); EAC (2023) (Ref_126)	Proposal under preparation

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
151	Upper Kolab	320	18.885	82.560	Odisha	Koraput	Odisha Hydro Power Corporation Limited	Off River open loop	Under Survey and Investigation	Granted	Feb_28_2020					CEA (2023a) (Ref_137)	Project found not feasible by CEA
152	Badrinagar	1980	27.580	76.450	Rajasthan	Alwa	Not Specified	On River	Fall in restricted area			Site fall in Tiger Forest Sariska (Wild Life Sanctuary).				CEA (2023a) (Ref_137)	Unexploitable at present - Fall in restricted area (CEA)
153	Barah	1800	27.480	76.400	Rajasthan	Alwa	Not Specified	On River	Fall in restricted area			Site fall in Tiger Forest Sariska (Wild Life Sanctuary).				CEA (2023a) (Ref_137)	Unexploitable at present - Fall in restricted area (CEA)
154	Brahmani	600	25.046	75.118	Rajasthan	Chittaurgarh	Acme Cleantech Solutions Private Limited	Off River	Proposal under preparation	Granted	Dec_11_2023					CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 1st EAC October 17-18, 2023
155	Rana Pratap Sagar	1200	24.852	75.686	Rajasthan	Chittorgarh	Semaliya Energy Private Limited	Off River closed loop	Proposal under preparation	Granted	Jan_24_2022					MoEF&CC (2024) (Ref_132)	MOM 31st EAC July 29, 2022
156	Semaliya-II	1200	25.070	75.124	Rajasthan	Chittorgarh	Semaliya energy	Off River closed loop	Proposal under preparation	Granted	June_7_2023					MoEF&CC (Ref_131.pdf); MoEF&CC (2024) (Ref_132)	MOM 44th EAC March 27-28, 2023
157	Shahpur	1800	25.190	77.182	Rajasthan	Baran	Greenko Energies Private Limited	Off River	Under Survey and Investigation	Granted	Apr_13_2020	Under Progress	FC-I: 15.03.2024	MOA-18.12.2021	Mar_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM_41_EAC_Feb_23_2023
158	Sirohi	1200	24.991	72.958	Rajasthan	Sirohi	Sasa Stone Private Limited	Off River closed loop	Proposal under preparation	Granted	Jun_13_2023		In Process			MoEF&CC (2024) (Ref_132); EAC MoEFCC (27-28.3.2023) (Ref_146)	Proposal under preparation
159	Sirohi	1200	24.991	72.958	Rajasthan	Sirohi	JSW Energy PSP One Limited	Off River closed loop	Under Survey and Investigation	Granted	July_5_2023			MOA-24.01.2022	Aug_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132); EAC	MOM_EAC

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
																(27.3.2023) (Ref_138)	
160	Sukhpura	2560	24.999	75.395	Rajasthan	Chittorgarh	Greenko Energies Private Limited	Off River closed loop	Under Survey and Investigation	Granted	Feb_28_2020			MOA-24.01.2023	Mar_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 29th EAC December 05, 2019
161	Aliyar	700	10.437	77.013	Tamilnadu	Coimbatore	Ernst & Young	On River	PFR prepared					MOA-23.01.2019	Feb_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 1st EAC July 29, 2020
162	Arunachalam	900	12.019	78.705	Tamilnadu	Dharamapuri and Tiruvannamalai	Volthills Private Limited	Off River closed loop	Proposal under preparation	Granted	Aug_7_2024					MoEF&CC (2024) (Ref_132)	MOM 42nd EAC Feb 23, 2023
163	Athur	300	10.304	77.754	Tamilnadu	Dindigul	TANGEDCO along with TATA Consultancy energy Pvt Ltd	On River	PFR prepared							CEA (2023a) (Ref_134); CEA (2023) (Ref_137)	MOM 43rd EAC March 07, 2023
164	Chattar	1100	8.464	77.376	Tamilnadu	Kanyakumari	TANGEDCO along with TATA Consultancy energy Pvt Ltd	On River	PFR prepared							EAC (27.3.2023) (Ref_138)	MOM_44_EAC_Mar_27_28_2023
165	Greenko TN01	1200	12.832	78.836	Tamilnadu	Tirupathur	Greenko Energies Private Limited	Off River closed loop	Proposal under preparation	Granted	June_7_2023					MoEF&CC (2024) (Ref_132)	MOM 48th EAC June 26-27, 2023
166	Kadamparai	400	11.017	76.960	Tamilnadu	Coimbatore	Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO)	On River	Operating in Pumping Mode							CEA (2023a) (Ref_137)	Cost of Generation will be very high; Break even period more than 25 Yrs
167	Karayar	1000	8.585	77.311	Tamilnadu	Tirunelveli	TANGEDCO along with TATA	On River	PFR prepared							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA

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							Consultancy energy Pvt Ltd										Status Report as on 31.5.2023
168	Kodayar	1500	8.505	77.311	Tamilnadu	Kanyakumari	Tamil Nadu Generation and Distribution Corporation	On River	Survey and Investigation Held up		Pre-DPR chapters returned after there is no progress in the S&I activities by the develop					CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
169	Kundah	500	11.377	76.572	Tamilnadu	Nilgiris	Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO	On River	Under Active Construction							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023
170	Manalar	1200	9.638	77.346	Tamilnadu	Theni	Tamil Nadu Generation and Distribution Corporation	Off River	Proposal under preparation	Granted	April_17_2023					CEA (2023a) (Ref_137; Ref_144)	PFR prepared by TANGEDCO
171	Manjalar	500	10.234	77.651	Tamilnadu	Dindigul/Theni	TANGEDCO along with TATA Consultancy energy Pvt Ltd	On River	PFR prepared							CEA (2023a) (Ref_137; Ref_144)	PFR prepared
172	Mettur	1000	11.783	77.617	Tamilnadu	Anthiyur	TANGEDCO along with TATA Consultancy energy Pvt Ltd	On River	PFR prepared							CEA (2023a) (Ref_137; Ref_144)	PFR prepared
173	Nallar	500	10.424	77.089	Tamilnadu	Coimbatore	THDCIL	On River	Project found not feasible							CEA (2023a) (Ref_137; Ref_144)	PFR prepared

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
174	Palar-Poranthalar	1100	10.314	77.453	Tamilnadu	Dindigul	TANGEDCO along with TATA Consultancy energy Pvt Ltd	On River	PFR prepared							CEA (2023a) (Ref_137; Ref_144)	PFR Prepared
175	Sandynalla	1200	11.444	76.652	Tamilnadu	Nilgiris	NTPC	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	PFR Prepared
176	Sigur	800	11.591	76.708	Tamilnadu	Nilgiris	NTPC	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	PFR Prepared
177	Sillahalla - I	1000	11.315	76.649	Tamilnadu	Nilgiris	Tamil Nadu Generation and Distribution Corporation	On River	Survey and Investigation Held up	Granted	Sept_23 _2020					CEA (2023) (Ref_137; Ref_144)	Operating since 1988
178	Sillahalla Stage-II	1000	11.280	75.800	Tamilnadu	Nilgiris and Coimbtore	Tamil Nadu Generation and Distribution Corporation	Off River open loop	Under Survey and Investigation							CEA (2023a) (Ref_137; Ref_144)	Active Construction - Likely commissioning by 2024-25 (Oct. 2024)
179	TN-01	1200	12.832	78.836	Tamilnadu	Tirupathur	Greenko Energies Private Limited	Off River closed loop	Additional Studies Recommended	EAC recommended for grant of Standard ToR for conducting EIA study						MoEF&CC (2024) (Ref_132); EAC MoEFCC (27-28.3.2023) (Ref_146)	Proposal under preparation
180	Upper Bhavani	1000	11.230	76.523	Tamilnadu	Nilgiris	NTPC	On River	Yet to be allotted							CEA (2023a) (Ref_144)	PFR Under Preparation
181	Velimalai	1100	8.140	77.320	Tamilnadu	Kanyakumari	TANGEDCO along with TATA Consultancy energy Pvt Ltd	Off River	PFR Under Preparation							CEA (2023a) (Ref_144)	Yet to be allotted by the State for development

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
182	Astha Telangana	600	18.574	78.518	Telangana	Nizamabad	Astha Green Energy Ventures India Private Limited	Off River closed loop	Proposal under preparation	Granted	June_7_2023					Greenco Energies PFR (Ref_127.pdf)	MOM_31_EAC_July_29_2022
183	Cerulean-II	640	19.443	79.442	Telangana	Komaram Bheem	Cerulean Energy Solutions Private Limited	Off River closed loop	Proposal under preparation	Granted	June_7_2023					MoEF&CC (2024) (Ref_132); EAC (2023) (Ref_126)	MOM_42_EAC_Feb_23_2023
184	Greenco TS01	750	19.572	78.334	Telangana	Adilabad	Greenko Energies Private Limited	Off River closed loop	Proposal under preparation	Granted	April_17_2023					MoEF&CC (2024) (Ref_132)	MOM_39_EAC_Dec_28_2022
185	Greenco TS02	1200	19.210	78.330	Telangana	Adilabad and Nirmal	Greenko Energies Private Limited	Off River closed loop	PFR prepared	Not Listed by MoEF&CC						MoEF&CC (2024) (Ref_132)	MOM 35th EAC Oct 11, 2022
186	Greenko TS01	750	19.572	78.334	Telangana	Adilabad	Greenko Energies Private Limited	Off River closed loop	Proposal under preparation	Granted	April_17_2023					MoEF&CC (2024) (Ref_132)	MOM 32nd EAC May 15, 2020
187	Ippagudem	3960	18.284	80.665	Telangana	Mulugu	Greenko Energies Private Limited	Off River closed loop	Proposal under preparation	Granted	July_13_2020					MoEF&CC (2024) (Ref_132); EAC (27.3.2023) (Ref_138)	MOM_44_EAC_Mar_27_28_2023
188	Nagarjuna Sagar	706	16.592	79.490	Telangana	Nalkonda	Telangana State Power Generation Corporation Limited (TSGENCO).	On River	Operating in Pumping Mode							CEA (2023a) (Ref_137; Ref_144)	Operating since 1970
189	Ranapur	1200	19.210	78.330	Telangana	Adilabad & Nirmal	Sri Siddharth Infratech & Services (I) Private Limited	Off River closed loop	Proposal under preparation	Granted	Dec_8_2022					CEA (2023) (Ref_137; Ref_144)	Operating since 2001
190	Srisailam LBPH	900	16.073	78.870	Telangana	Mahabubnagar	Telangana State Power Generation Corporation	On River	Operating in Pumping Mode							MoEF&CC (2024) (Ref_132); EAC (2023) (Ref_126)	Proposal under preparation

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
							Limited (TSGENCO)										
191	Astha UP	640	24.857	82.108	Uttar Pradesh	Mirzapur and Prayagraj	Astha Green Energy Ventures India Private Limited	Off River closed loop	Proposal under preparation	Granted	June_13_2023		In Progress	MOA-01.02.2023	May_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM_41st_EAC_Feb_15_ 2023
192	Chichlik	1560	24.541	83.438	Uttar Pradesh	Sonbadhra	Avaada Waterbattery private limited	Off River closed loop	Under Environmental Clearence Process	EAC recommended the proposal for grant of Standard ToR for conducting EIA study						MoEF&CC (2024) (Ref_132)	MOM 44th EAC March 27-28, 2023
193	Greenco UP01	3660	24.528	83.313	Uttar Pradesh	Sonbhadra	Greenko Energies Private Limited	Off River	Under Survey and Investigation	Granted	Jan_24_ 2022					MoEF&CC (2024) (Ref_132); EAC (27.3.2023) (Ref_138)	MOM 44th EAC March 27-28, 2023
194	Kandhaura	1680	24.479	83.134	Uttar Pradesh	Sonbadhra	JSW Energy PSP Six Limited	Off River closed loop	Under Survey and Investigation	Granted	April_16_2024					MoEF&CC (2024) (Ref_132)	MOM 48th EAC June 26-27, 2023
195	Musakhand	600	24.98	83.22	Uttar Pradesh	Chandauli	Acme Cleantech Solutions Private Limited	Off River closed loop	Under Survey and Investigation	Applied for amendment	Sept_23_2023					MoEF&CC IA Division (09/05/2024) (Ref_141)	EC/MOM/EAC/ 408274/4/2024
196	Shoma	2400	24.538	83.365	Uttar Pradesh	Sonbhadra	Torrent Power Limited	Off River closed loop	Under Survey and Investigation	Granted	Aug_7_ 2023		In Process	MOA-25.11.2022	May_2024	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	MOM 9th EAC March 20, 2024
197	Sonbhadra	1200	24.553	83.185	Uttar Pradesh	Sonbhadra	Sri Siddharth Infratech & Services (I) Private Limited	Off River closed loop	Proposal under preparation	Granted	June_7_ 2023		In Process	MOA-'03.04.2023	Feb_2025	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	Under Survey and Investigation

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
198	Jaspalgarh	1935	29.897	78.384	Uttrakhand	Garhwal	THDCIL	On River	Fall in restricted area							CEA (2023a) (Ref_137)	PSP fall in Rajaji National Park and its Buffer Zon
199	Kandhaura	1680	24.479	83.134	Uttrakhand	Sonbhadra	JSW Energy PSP Six Limited	Off River closed loop	Under Survey and Investigation	Granted	April_16_2024					CEA (2023a) (Ref_137; Ref_144)	Active Construction - Likely commissioning by 2024-25 (Sept.'24)
200	Musakhand	600	24.983	83.222	Uttrakhand	Chandauli	Acme Cleantech Solutions Private Limited	Off River closed loop	Under Survey and Investigation	Applied for amendment	Sept_23_2023		In Process	MOA-'03.04.2023	Feb_2025	CEA (2024c); MoEF&CC (2024) (Ref_164; Ref_132)	Under Survey and Investigation
201	Sashnai	1760	24.522	83.179	Uttrakhand	Sonbhadra	Torrent Power Limited	Off River closed loop	Proposal under preparation	Granted	Dec_14_2023					MoEF&CC (2024) (Ref_132); EAC (2023) (Ref_147)	Proposal under preparation
202	Tehri St II	1000	30.375	78.430	Uttrakhand	Tehri	THDC	On River	Under Active Construction				In Process			MoEF&CC (2024) (Ref_132); EAC (2024) (Ref_145)	Under Survey and Investigation
203	Bahalpur Standalone	1380	23.365	82.810	West Bengal	Purulia	Greenko Energies Private Limited	Off stream closed loop	Proposal Withdrawn							EAC (2021) (Ref_135)	MOM20th_RVHEPEAC_14-12-2021
204	Bandhu	900	23.233	86.156	West Bengal	Purulia	WBSEDCL	On River	Proposal under preparation	Granted	March_20_2019					EAC (2021) (Ref_135)	MOM20th_RVHEPEAC_14-12-2022
205	Greenco WB01	1380	23.301	86.067	West Bengal	Purulia	Greenko Energies Private Limited	Off stream closed loop	EAC deferred the Proposal - Additional Study Required		More Environmental aspects to be studied					CEA (2023a) (Ref_137)	CEA Report June 2023
206	Kathlajal	900	23.174	86.153	West Bengal	Purulia	Not specified	On River	Project considered by CEA for							CEA (2023a) (Ref_137; Ref_144)	CEA Report June 2023; CEA Status Report as on 31.5.2023

S.No	PSP Name	Capacity (MW)	Lat.	Long.	State	District	Promotor	Type of PSP	Development Status	TOR by MoEF &CC	Date of TOR Grant	Environmental Clearence (MoEF&CC)	Date of Grant/ status FC	Memorandum of Agreement	DPR Target Date	Reference	Remark
									further study								
207	Kulbera	1110	23.257	86.026	West Bengal	Purulia	DVC	On River	Yet to be allotted							CEA (2023a) (Ref_137; Ref_144)	DPR Concurred on 05.10.2016
208	Panchet	40	23.681	86.748	West Bengal	Purlia	Not Specified	On River	Proposal Withdrawn							CEA (2023a) (Ref_137; Ref_144)	PFR under preparation
209	Panchet Hill	1000	23.630	86.764	West Bengal	Purulia	DVC	On River	Yet to be allotted							CEA (2023a) (Ref_137)	CEA Report June 2023
210	Purulia	900	23.332	86.370	West Bengal	Purulia	West Bengal State Electricity Distribution Company Limited (WBSEDCL)	On River	Operating in Pumping Mode							CEA (2023a) (Ref_137; Ref_144)	Operating
211	Turga	1000	23.213	86.072	West Bengal	Purulia	WBSEDCL	On River	DPR Concurred by CEA			EC: 02.07.2018	FC-I: 12.04.2018; FC-II: 13.10.2022			CEA (2023a) (Ref_137)	Project was removed from CEA list (16_Aug_2021)

Data Source used to compile data the present study on PSP sites - identified, developed, under various stages of development or dropped due to various reasons

CEA (Central Electricity Authority) (2024c). Pumped storage potential in country (India) (As on Sept..2024) (https://cea.nic.in/pumped-storage-plants/?lang=en) Accessed on Sept. 11' 2024		
CEA (Central Electricity Authority) (2024d). Pumped storage potential in country (India) (As on 30.6.2024) (https://cea.nic.in/hpi/auto-draft-53/?lang=en)	Ref_155.pdf	Table
CEA (Central Electricity Authority) (2024). Pumped storage potential in country (India) (As on 29.2.2024) (https://cea.nic.in/wp-content/uploads/hpi/2024/02/Pumped_Storage_potential_in_the_country-1.pdf)	Ref_125.pdf	Report
EAC (2023) MoM_42_EAC_River_valley_23_02_2023 MINUTES OF THE 42ND MEETING OF THE EXPERT APPRAISAL COMMITTEE FOR RIVER VALLEY AND HYDROELECTRIC PROJECTS HELD ON 23RD FEBRUARY, 2023 (https://web.archive.org/web/20230327113431/https://environmentclearance.nic.in/writereaddata/Form-1A/Minutes/2103202385039222FinalMoM_42_EAC_River_valley_23_02_2023.pdf)	Ref_126.pdf	Minutes of Meeting
Greenco Energies pvt Ltd (2022) Pre Feasibility Report (PFR) GREENKO TS02 OFF-STREAM CLOSED LOOP PUMPED STORAGE PROJECT (1200 MW) (https://environmentclearance.nic.in/writereaddata/Online/TOR/12_Jul_2022_16331855334073881PFR.pdf) Accessed on 27.7.2024	Ref_127.pdf	PFR Report
Greenco Energies pvt Ltd (2020) Pre Feasibility Report (PFR) UKAI STANDALONE PUMPED STORAGE PROJECT (2400 MW) (https://environmentclearance.nic.in/DownloadPfdFile.aspx?FileName=KFM34jhn7XYobt0qtAyYDIOaeNos/wc8sF45wQnPtibUeId6ZPQReHqVusj5rlkOZNKezRohaSayIauz3PsobRSgiVnVIkyFqhH6aQXgtBPdlzbIozDrMBC0XJHAurh9fO2j4cTOph/K391FTCYAFvADnuKX1C7VbNwtoIExeVPMgIa/ZfrZ+1f+fAcKvTde&FilePath=93ZZBm8LWEXfg+HAlQix2fE2t8z/pgnoBhDlYdZCxzXmG8GlihX6H9UP1HygCn3pCkAF2zPFXFQNqA4krKa1Aw==) Accessed on 27.7.2024	Ref_128.pd	PFR Report
Greenco Energies pvt Ltd (2019) Pre Feasibility Report (PFR) MHAISMAL STANDALONE PUMPED STORAGE PROJECT (800MW) (https://environmentclearance.nic.in/writereaddata/Online/TOR/12_Nov_2019_002841677GAFCFEQ8PFR.pdf) Accessed on 27.7.2024	Ref_129.pdf	PFR Report
Adani Green Energy Limited (2022) PATGAON PUMPED STORAGE PROJECT (2,100 MW) (https://environmentclearance.nic.in/writereaddata/Online/TOR/13_Aug_2022_10411660069186137PFR.pdf) Accessed on 27.7.2024	Ref_130.pdf	PFR Report
MoEF&CC (March 2023) Proposals considered for deliberation in the Expert Appraisal Committee (SONBHADRAPSP, Greenko TN01 PSP, Cerulean-II, Semaliya-II and Astha Telangana) https://environmentclearance.nic.in/writereaddata/Form-1A/Agenda/_17032023M62EYN32.pdf	Ref_131.pdf	Meeting Agenda
MoEF&CC (June 30' 2024) List of Pumped Storage Projects granted ToR by MoEF&CC (As on June 30th 2024) (https://cea.nic.in/wp-content/uploads/pumpedstorage/2024/06/List_of_Pumped_Storage_Projects_granted_ToR_by_MoEFCC.xlsx)	Ref_132.xlxs	Excel Sheet (Records)
TATA (Aug. 2021) Feasibility Report - Kurukutti Pumped Storage Project (1200 MW) Vizianagaram District, Andhra Pradesh, TATA Consulting Engineers Limited (https://environmentclearance.nic.in/writereaddata/Online/TOR/11_Oct_2021_11414961045458643PFR.pdf) Accessed on 28.7.202	Ref_133.pdf	PFR Report
CEA (Central Electricity Authority) (2023). Pumped storage potential in country (India) (As on 31.7.2023) (https://cea.nic.in/wp-content/uploads/hpi/2023/07/PSPStatus_in_country.pdf)	Ref_134.pdf	Table
EAC (2021) MINUTES OF THE 20TH MEETING OF THE EXPERT APPRAISAL COMMITTEE FOR RIVER VALLEY AND HYDROELECTRIC PROJECTS HELD ON 14TH DECEMBER, 2021 FROM 10:30 AM – 3:00 PM THROUGH VIDEO CONFERENCE (Regarding withdraw of the proposal due to mistakes done in Form 1.Bahalpur Standalone PSP (1380MW)) (https://environmentclearance.nic.in/writereaddata/Form-1A/Minutes/0601202227705589Corrected_FinalMOM20th_RVHEPEAC_14-12-2021.pdf)	Ref_135.pdf	Minutes of Meeting
EAC (Expert Appraisal Committee) (11.10.2022) Ministry of Environment, Forest and Climate Change (MoEF&CC) - Agenda of Expert Appraisal Committee - Meeting ID : IA/RIV/13345/11/10/2022 (Regarding CHIREC PSP (75MW), Surajpur, Chhatisgarh) (https://environmentclearance.nic.in/writereaddata/Form-1A/Agenda/_29092022PTW6LDRV.pdf)	Ref_136.pdf	Meeting Agenda
CEA (2023a) REASSESSMENT OF 0NRIVER PUMPED STORAGE HYDROELECTRIC POTENTIAL IN INDIA, Central Electricity Authority, Ministry of Power. Pp. 528. (https://cea.nic.in/wp-content/uploads/hp___i/2023/08/Pumped_Storage_On_River_Final_compressed.pdf)	Ref_137.pdf	Report
EAC (27.3.2023) MINUTES OF THE 44TH MEETING OF THE EXPERT APPRAISAL COMMITTEE FOR RIVER VALLEY AND HYDROELECTRIC PROJECTS HELD ON 27TH – 28TH MARCH, 2023 FROM 10:30 AM – 05.30 PM THROUGH VIDEO CONFERENCE. (https://environmentclearance.nic.in/writereaddata/Form-1A/Minutes/2504202398975110Final_MoM_44_EAC_River_valley_27_03_2023.pdf)	Ref_138.pdf	Minutes of Meeting
EAC MoEF&CC (18/12/2023)MoM ID: EC/MOM/EAC/603648/11/2023 Minutes of 4th EXPERT APPRAISAL COMMITTEE MEETING OF meeting River Valley and Hydroelectric Projects held from 24/11/2023 to 24/11/2023 (Regarding Yadaballi PSP (1200MW) - EAC Returned the proposal in present form) (https://parivesh.nic.in/utildoc/32508716_1702893778315.pdf)	Ref_139.pdf	Minutes of Meeting
Greenco (2018) Prefeasibility Report for Saundatti INTEGRATED RENEWABLE ENERGY WITH STORAGE PROJECT (IRESP) https://environmentclearance.nic.in/writereaddata/Online/TOR/16_Apr_2018_123630363PJWJ2GJTSaundattiIRESPPFRfinalToR.pdf)	Ref_140.pdf	Report (PFR)
MoEF&CC IA Division (09/05/2024) (MoM ID: EC/MOM/EAC/408274/4/2024) Minutes of AGENDA OF 10TH MEETING OF THE EXPERT APPRAISAL COM MITTEE meeting River Valley and Hydroelectric Projects held from 29/04/2024 to 29/04/2024 (Regarding Chichlik PSP (1560 MW) Sonbadhra, Uttar Pradesh & Shirawta PSP (1800 MW), Maharastra) (https://parivesh.nic.in/utildoc/66590421_1715236014369.pdf)	Ref_141.pdf	Minutes of Meeting

MoEF&CC IA Division (01/04/2024) (MoM ID: EC/MOM/EAC/754327/3/2024) Minutes of 9th MEETING OF THE EXPERT APPRAISAL COMMITTEE OF meeting River Valley and Hydroelectric Projects held from 20/03/2024 to 20/03/2024	Ref_142.pdf	Minutes of Meeting
MoEF&CC MINUTES OF THE 20TH MEETING OF THE EXPERT APPRAISAL COMMITTEE FOR RIVER VALLEY AND HYDROELECTRIC PROJECTS HELD ON 14TH DECEMBER,2021 FROM 10:30 AM – 3:00 PM THROUGH VIDEO CONFERENCE.		
CEA (2023) PUMPED STORAGE POTENTIAL IN THE COUNTRY - State-wise List of ON River Pumped Storage Projects (Status as on 31.5.2023) (https://cea.nic.in/wp-content/uploads/hpi/2023/05/Pumped_storage_potential_in_the_country.pdf)	Ref_144.pdf	Table
MoEF&CC IA Division (08/01/2024) (EC/MOM/EAC/306350/12/2023) Minutes of 5TH EAC meeting River Valley and Hydroelectric Projects held from 19/12/2023 to 20/12/2023 Regarding Gadikota PSP (1200 MW) Andhra Pradesh (https://parivesh.nic.in/utildoc/37328773_1704718073375.pdf)	Ref_145.pdf	Minutes of Meeting
EAC MoEFCC (27-28.3.2023) MINUTES OF THE **44TH** MEETING OF THE EXPERT APPRAISAL COMMITTEE FOR RIVER VALLEY AND HYDROELECTRIC PROJECTS HELD ON 27TH – 28TH MARCH, 2023 (https://environmentclearance.nic.in/writereaddata/Form-1A/Minutes/2504202398975110Final_MoM_44_EAC_River_valley_27_03_2023.pdf)	Ref_146.pdf	Minutes of Meeting
EAC MoEFCC (10-11/11/2023) Minutes of 3RD MEETING OF THE EXPERT APPRAISAL COMMITTEE FOR RIVER VALLEY AND HYDROELECTRIC PROJECTS meeting River Valley and Hydroelectric Projects held from 10/11/2023 to 10/11/2023 (https://parivesh.nic.in/utildoc/26617887_1700822666696.pdf)	Ref_147_pdf	Minutes of Meeting
EAC MoEFCC (19/02/2024) (MoM ID: EC/MOM/EAC/605713/2/2024) Minutes of 7TH MEETING OF EXPERT APPRAISAL COMMITTEE meeting River Valley and Hydroelectric Projects held from 09/02/2024 to 09/02/2024 (Regarding Rauni (2100 MW) and Dangari (1400 MW PSP) (https://parivesh.nic.in/utildoc/48184428_1708350530465.pdf)	Ref_148.pdf	Minutes of Meeting

ANNEXURE-4: PUMPED STORAGE PROJECTS GRANTED TOR, EC & FC BY MOEF&CC (STATUS AS ON 30.4.2025)
(Source: https://cea.nic.in/pumped-storage-plants/?lang=en)

S.No	District	Pumped Storage Project	Installed Capacity	Type of PSP	Company	Date of Grant of TOR	Status of EC &FC		PPS status
							Date of Grant/ status EC	Date of Grant/ status FC	
Status of TOR, EC & FC for PSPs since 2019									
Andhra Pradesh									
1	Visakhapatnam	Upper Sileru	1350	Open Loop	Andhra Pradesh Power Generation Corporation Limited	03-06-19	**EC** proposal discussed. ADS raised	Pending in MoEF&CC after recommendation of State Govt. for FC-I	PPS vetted on 05.01.2021
2	Kadapa	Veeraballi	1800	Off-stream closed loop	Astha Green Energy Ventures India Pvt Ltd	13-07-20		In process	PPS conditionally cleared by HPA on 16.06.2023
3	Anantapur	Chitravathi	500	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	18-10-21	**EC:** 28/08/2023 ; transfer of EC application submitted- ADS raised.	FC: not required	PPS vetted by HPA on 27.01.2023
4	Vizianagaram	Kurukutti	1200	Open Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	16-12-21			
5	Vizianagaram	Karrivalasa	1000	Open Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	16-12-21			

S.No	District	Pumped Storage Project	Installed Capacity	Type of PSP	Company	Date of Grant of TOR	Status of EC &FC		PPS status
							Date of Grant/ status EC	Date of Grant/ status FC	
6	Kadapa	Gandikota	1000	Open Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	04-01-22	EC: EC proposal discussed in EAC in Oct 23, deferred for ADS;	In process	PPS Conditionally vetted by HPA on 18.05.2022
7	Kurnool	Owk	800	Open Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	04-01-22			PPS Conditionally vetted by HPA on 06.04.2022
8	Visakhapatnam	Yerravaram	1200	Open Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	24-01-22			PPS Conditionally vetted by HPA on 01.06.2022
9	Kadapa	Somasila	900	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	29-06-22		In process	PPS Conditionally vetted by HPA on 08.03.2022
10	Anantapur	Singanamala	800	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	13-02-23	EC proposal submitted in Feb 24, EDS raised	In process	PPS Conditionally Vetted by HPA on 07.11.2022
11	YSR	Paidipalem North	1000	Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	17-04-23			
12	YSR	Paidipalem East	1200	Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	17-04-23			

S.No	District	Pumped Storage Project	Installed Capacity	Type of PSP	Company	Date of Grant of TOR	Status of EC &FC		PPS status
							Date of Grant/ status EC	Date of Grant/ status FC	
13	YSR	Vempalli	1500	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	07-08-23		In process	PPS proposal conditionally vetted vide HPA letter dated 12-10-2023.
14	Ananthapuramu	Kamalapadu	950	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	07-08-23			
15	Alluri Sitharama Raju	Gujjili	1500	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	07-08-23			
16	Nandyal	Yaganti	1000	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	07-08-23			
17	Alluri Sitharama Raju	Chittamvalasa	800	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	10-09-23			
18	Anakapalli and Vizianagaram	Raiwada	850	Close Loop	Adani Green Energy Limited	25-10-23		In process	observations furnished by HPA on 08.01.2024.
19	Annamayya	Rayavaram	1500	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	30-01-24			
20	Annamayya	Gadikota	1200	Off-Stream Closed Loop	New And Renewable Energy Development Corporation Of Andhra Pradesh Ltd (NREDCAP)	30-01-24			

S.No	District	Pumped Storage Project	Installed Capacity	Type of PSP	Company	Date of Grant of TOR	Status of EC &FC		PPS status
							Date of Grant/ status EC	Date of Grant/ status FC	
21	Alluri Sitharama Raju	Pedakota	1800	Open Loop	Adani Green Energy Limited	14.08.2024			
		Total (Ar. Pr.)	**23850**						
Chhattisgarh									
22	Surajpur	Chikni	325	on-stream open loop	Chikini Energy Private Limited	07-08-23			
23	Surajpur	Kharauli	500	on-stream open loop	Kharauli Energy Private Limited	10-09-23			
24	Korba	Hasdeo Bango	1200	Open Loop	Chhattisgarh State Power Generation Company Limited	10-01-24			
25	Surguja	CHH-09	1200	Off-Stream Closed Loop	Sterlite Grid 36 Limited	22-01-24			
26	Surguja	Gandhwani	1200	off-stream Closed loop	Gandhwani Energy Private Limited	05-02-24			
27	Bilaspur	Bilaspur	1000	off-stream Closed loop	Jindal Renewable Power Private Limited	23.10.2024			
28	Jashpur	Rouni	2100	r Off Stream	Chhattisgarh State Power Generation Company Limited	07.09.2024			
29	Jashpur	Dangari	1400	Closed Loop	Chhattisgarh State Power Generation Company Limited	23.10.2024			
30	Gariaband	Sikaser	1200	open Loop	Chhattisgarh State Power Generation Company Limited	26.12.2024			
		Total (Chhattisgarh)	**9125**						
Gujarat									

S.No	District	Pumped Storage Project	Installed Capacity	Type of PSP	Company	Date of Grant of TOR	Status of EC &FC		PPS status
							Date of Grant/ status EC	Date of Grant/ status FC	
31	Tapi	Ukai	2400	Off Stream closed loop	Greenko Energies Private Limited	13-04-20			
32	Valsad	Pindval	1000	Closed Loop	Torrent Power Limited	23-09-23			
33	Valsad	Tokarpada	1300	Closed Loop	Torrent Power Limited	23-09-23			
34	Tapi	Amalpada	300	Off Stream closed loop	Gujarat State Electricity Corporation Limited	06.10.2024			
35	Tapi	Juni Bavli	450	Open Loop	Gujarat State Electricity Corporation Limited	30.09.2024			
36	Tapi	Juni Kayaliwel	300	Off Stream closed loop	Gujarat State Electricity Corporation Limited	02.10.2024			
37	Tapi	Satkashi	330	Off Stream closed loop	Gujarat State Electricity Corporation Limited	06.10.2024			
38	Tapi	Serula	960	Off Stream closed loop	Gujarat State Electricity Corporation Limited	30.09.2024			
39	Banas Kantha	Dharoi	500	Off-Stream Open loop	Gujarat State Electricity Corporation Limited	15.03.2025			
		Total (Gujarat)	**7540**						
Karnataka									
40	Davanagere	Shanti Sagar	270	Open Loop	Cerulean Energy Solutions Private Limited	17-01-20			
41	Bellary	Vijayanagar	130	off-stream closed loop pumped	JSW Renewable Energy (Vijayanagar) Limited	03-06-22	EC: recommended in Nov. 23 ; ADS raised.		
42	Ballari	Narihalla	300	Open Loop	JSW Energy PSP Three Limited	05-07-23		In process	
43	Kalaburagi	Sankanoor	300	Off-Stream Closed Loop	Cerulean Energy Solutions Private Limited	07-08-23			

S.No	District	Pumped Storage Project	Installed Capacity	Type of PSP	Company	Date of Grant of TOR	Status of EC &FC		PPS status
							Date of Grant/ status EC	Date of Grant/ status FC	
44	Uttara Kannada	Sharavathy	2000	Open Loop	Karnataka Power Corporation Limited	14-12-23		In process	CCEA cleared
		Total (Karnataka)	**3000**						
Madhya Pradesh									
45	Neemuch	MP 30 Gandhi Sagar	1440	Open Loop	Greenko Energies Private Limited	28-02-20	01-12- 2021 and its amendment Transfer of EC with dated: 13-02- 2023;	FC-II: 09.06.2023	Earlier PPS was conditionally vetted on 29.10.2021 for Installed Capacity of 1440 MW. HPA Division vide letter dated 28.03.2024 again conditionally vetted the PPS for revised inlled capacity of 1920 MW.
46	Satna	Panari	1800	Open Loop	Sri Siddharth Infratech & Services (I) Private Limited	13-03-20		In process	PPS Returned. Deleted from list of projects under S&I .
47	Khargone	Astha MP	1200	Off-Stream Closed Loop	Astha Green Energy Ventures India Private Limited	17-04-23			
48	Panna	MP Pumped Storage Project	600	Off-Stream Closed Loop	Rithwik Projects Private Limited	13-06-23			
49	Rewa	Rewa	600	Off-Stream Closed Loop	Sasa Stone Private Limited	13-06-23			
50	East Nimar	Indirasagar-Omkareshwar	640	on-stream open loop	NHDC	11.01.2025			
		Total (Madhya Pr.)	**6280**						
Maharashtra									

S.No	District	Pumped Storage Project	Installed Capacity	Type of PSP	Company	Date of Grant of TOR	Status of EC &FC		PPS status
							Date of Grant/ status EC	Date of Grant/ status FC	
51	Aurangabad	Mhaismal	800	Closed Loop	Greenko Energies Private Limited	28-02-20			
52	Aurangabad	Nayagaon	2000	Closed Loop	Greenko Energies Private Limited	13-04-20		delisted	
53	Nashik	Bhavali	1500	Off-Stream Open Loop	JSW Energy PSP Two Limited	27-06-22	EC: proposal submitted on 18.06.2024. ADS raised		PPS Conditionally Vetted by HPA on 16.09.2022
54	Kolhapur	Patgaon	2100	Open Loop	Adani Green Energy Limited	09-11-22			PPS conditionally cleared by HPA on 18.08.2023
55	Satara	Tarali	1500	Off Stream Open Loop	Adani Green Energy Limited	09-11-22	EC: 11.02.2025		PPS conditionally cleared by HPA on 07.07.2023
56	Pune	Warasgaon Warangi	1200	Open Loop	Adani Green Energy Limited	13-02-23			PPS conditionally vetted on 16.07.2024
57	Pune	Malshej Ghat Bhorande	1440	Closed Loop	Adani Green Energy Limited	3/24/2023; amendment in TOR applied			PPS conditionally vetted on 09.07.2024
58	Kolhapur	Kolhapur	1200	off stream closed Loop	Rithwik Projects Private Limited	13-06-23			
59	Satara	Koyna-Nivakane	2450	Closed Loop	Adani Green Energy Limited	07-08-23			PPS under examination in HPA
60	Raigarh	Bhivpuri	1000	Open Loop	The Tata Power Co. Ltd.	23-09-23	EC: proposal submitted, ADS raised	Pending at State Secretary due to EDS by MoEFCC, HQ	PPS conditionally cleared by HPA on 20.03.2024
61	Pune	Shirawta	1800	off stream Open Loop	The Tata Power Co. Ltd.	9/23/2023; amendment of TOR applied		In process at DFO level	

S.No	District	Pumped Storage Project	Installed Capacity	Type of PSP	Company	Date of Grant of TOR	Status of EC &FC		PPS status
							Date of Grant/ status EC	Date of Grant/ status FC	
62	Pune and Raigarh	Saidongar-2	1200	Open Loop	Torrent Power Limited	23-09-23			
63	Pune and Raigarh	Saidongar-1	3000	Open Loop	Torrent Power Limited	23-09-23		In process by MS for PSC-I	
64	Pune and Raigarh	Pane	1500	off steam Open Loop	JSW Energy PSP Seven Limited	1/30/2024, amendment 03.12.2024		In process at DFO level	PPS conditionally vetted by HPA on 26.06.2023
65	Pune and Raigad	Pawana Falyan	1500	Open Loop	Avaada Hydropower Battery Private Limited	21.10.2024			
66	Jalgaon and Aurangabad	Ghosla	2000	closed loop	Megha Engineering & infrastructures Limited	18.02.2025			
		Total (Maharashtra)	**26190**						
Odisha									
67	Koraput	Upper Kolab	320	Open Loop	Odisha Hydro Power Corporation Limited	28-02-20			
68	Malkangiri	Balimela	500	open Loop	Odisha Hydro Power Corporation Limited	21-05-20			
69	Kalahandi	Greenko OD01	1200	ff-Stream Closed Loop	Greenko Energies Private Limited	17-04-23			
70	Kalahandi	Upper Indravati	600	open Loop	Odisha Hydro Power Corporation Limited	14-12-23			PPS conditionally vetted by HPA on 07.08.2020
71	Keonjhar	Ramial Left	1500	Closed Loop	Renew Solar Power Private Limited	15-01-24			
72	Deogarh	Tainsar	675	Off Stream closed loop	Jindal Renewable Power Private Limited	22-01-24			
		Total (Odisha)	**4795**						
Rajasthan									

73	chittorgarh	Sukhpura	2560	off stream closed loop	Greenko Energies Private Limited	2/28/2020, amendment in TOR: 03.12.2024	EC: 28.01.2025		PPS vetted by HPA on 16.01.2023.
74	Baran	Shahpur	1800	off stream closed loop	Greenko Energies Private Limited	13-04-20	**EC**: proposal submitted to MoEF&CC for EC and is under examination	FC-I: 15.03.2024	PPS conditionally cleared by HPA on 31.07.2023
75	chittorgarh	Rana Pratap Sagar	1200	Closed Loop	Semaliya Energy Private Limited	24-01-22			
76	chittorgarh	Semaliya-II	1200	Closed Loop	Semaliya Energy Private Limited	07-06-23			
77	Sirohi	Sirohi	640	Closed Loop	Sasa Stone Private Limited	13-06-23		In process	
78	Sirohi	Sirohi	1200	off stream closed loop	JSW Energy PSP One Limited	05-07-23			PPS conditionally vetted by HPA on 06.06.2023.
79	Chittaurgarh	Brahmani	600	Closed Loop	Acme Cleantech Solutions Private Limited	11-12-23			
80	Barmer	Balotra	1800	Closed Loop	Adani Green Energy Ltd.	28.01.2025			
		Total (Rajasthan)	**11000**						
Tamil Nadu									
81	The Nilgiris	Kundah	500	open Loop	Tamil Nadu Generation And Distribution Corporation	05-06-20	EC: 12.02.2021		
82	The Nilgiris	Sillahalla-I	1000	open Loop	Tamil Nadu Generation and Distribution Corporation	23-09-20			
83	Theni	Manalar	1200	open Loop	Tamil Nadu Generation and Distribution Corporation	17-04-23			
84	Tirupathur	Greenko TN01	1200	Closed Loop	Greenko Energies Private Limited	07-06-23			
85	Dharamapuri and Tiruvannamalai	Arunachalam	900	Closed Loop	Volthills Private Limited	07-08-23			

86	Tiruvannamalai	Tiruvannamalai	2000	Closed Loop	Eco Leap Technologies India Private Limited	21.10.2024			
87	Salem	Greenko TN-11	1000	Closed Loop	Greenko Energies Private Limited	21.10.2024			
		Total (Tamil Nadu)	**7800**						
Telangana									
88	Mulugu	Ippagudem	3960	Closed Loop	Greenko Energies Private Limited	13-07-20			
89	Adilabad	Ranapur	1200	Off-Stream Closed Loop	Sri Siddharth Infratech & Services (I) Private Limited	08-12-22			
90	Adilabad	Greenko TS01	750	Off-Stream Closed Loop	Greenko Energies Private Limited	17-04-23			
91	Nizamabad	Astha Telangana	600	Off-Stream Closed Loop	Astha Green Energy Ventures India Private Limited	07-06-23			
92	Komarambheem	Cerulean-II	640	Off-Stream Closed Loop	Cerulean Energy Solutions Private Limited	07-06-23			
		Total (Telangana)	**7150**						
Uttar Pradesh									
93	Sonbhadra	Greenko UP01	3660	off stream closed loop	Greenko Energies Private Limited	1/24/2022, amendment in 24/03/2023	EC: proposal submitted, ADS raised	In process	PPS conditionally cleared by HPA on 16.07.2023
94	Sonbhadra	Sonbhadra	1200	Closed Loop	Sri Siddharth Infratech & Services (I) Private Limited	07-06-23			
95	Mirzapur and Prayagraj	Astha UP	640	Closed Loop	Astha Green Energy Ventures India Private Limited	13-06-23			
96	Sonbhadra	Shoma	2400	off stream closed loop	Torrent Power Limited	07-08-23			
97	Chandauli	Musakhand	600	off stream closed loop	Acme Cleantech Solutions Private Limited	9/23/2023 applied for amendment		Pending at UA due to EDS	PPS vetted by HPA on 05.02.2024
98	Sonbhadra	Sashnai	1760	Closed Loop	Torrent Power Limited	14-12-23			

99	Sonbhadra	Kandhaura	1680	off stream closed loop	JSW Energy PSP Six Limited	16.04.2024		In process	
100	Sonbhadra	Chichlik	1560	off stream closed loop	Avaada Waterbattery Private Limited	27.05.2024			
101	Sonbhadra	Jhariya	1620	off stream closed loop	Jhariya Ananturja Pvt. Ltd.	07.09.2024			
102	Sonbhadra	Panaura	1500	off stream closed loop	Adani Green Energy Limited	07.09.2024			
		Total (U.P)	**16620**						
West Bengal									
103	Purulia	Bandu	900	open Loop	WBSEDCL	20-03-19			
		Total (W.B)	**900**						
		Total (MW)	**124250**						
Projects granted TOR before 2019									

S.No	State Name	District	Pumped Storage Project	Type of PSP	Installed Capacity	Company	Date of Grant of TOR	Status of EC &FC	
								Date of Grant/ status EC	Date of Grant/ status FC
1	**Karnataka**	Belagavi	Saundatti	Closed Loop	1200	Greenko Solar Energy Pvt. Ltd transfer to Greenko KA01 IREP Pvt. Ltd/	18.5.2018 amended 25.09.2018; transfer of EC proosal submitted on 28.11.23; ADS raised	EC: 19.09.22 amended 24.03.2023;	FC-I: 18.12.2018 , FC-II pending
2	**Andhra Pradesh**	Kurnool	Pinnapuram	Closed Loop	1200	Greenko Solar Energy Pvt. Ltd		EC: 14.07.2020	FC-I: 23.05.2020; FC-II: 24.05.2021
3	**West Bengal**	Purulia	Turga	Closed Loop	1000	WBSEDCL		EC: 02.07.2018	FC-I: 12.04.2018; FC-II: 13.10.2022
			Total (MW)		**3400**				

ANNEXURE-5: NEW PSP PROJECTS UNDERTAKEN FOR DEVELOPMENT DURING RECENT TIMES

Adani Green Energy has received a award letter during Feb. 2025 from uttar Pradesh Power Corporation for Panaura PSP (1,250 MW) to be developed in Soanbhadra district of Uttar Pradesh. The project is expected to be completed in next 6 years (https://www.mercomindia.com/adani-green-1250-mw-pumped-storage-uppcl).,

"The Andhra Pradesh, Gujarat, and Maharashtra state governments have inked agreements with NHPC for PSP projects. Additionally, in August 2023, NHPC and Andhra Pradesh Power Generation Corporation (APGenco) signed a Memorandum of Understanding for a PSP project. Additionally, in August of last year, APGenco requested prequalification bids for an EPC contractor to equip and build the 1,350 MW Upper Sileru project. For the Shirawta (1,800 MW) PSP and Bhivpuri (1,000 MW) PSP projects, Tata Power and the Maharashtra government inked an MOU in August 2023. An estimated US$ 1.56 billion will be invested in these two Western Ghats projects (Burdett, 2024).

NHPC entered into a MoU with GPCL during January 3rd 2024. to invest Rs 4,000 crore in 750 MW Kuppa PSP Project at Chhota Udaipur in Gujarat (MoP, 2024). Similarly, NHPC and APGENCO has also entered into an MoU in August 2023, to develop PSP and renewable energy projects. As per this MoU in initial phase, implementation of two PSP projects namely; Kamlapadu (950 MW) and Yaganti (1,000 MW) of a total capacity 1,950 MW will be undertaken. The projects, will be executed as joint ventures (MoP,2023a). Earlier, in June 2023, NHPC and the Department of Energy of the Maharashtra Government signed an MoU for the development of PSP and other RE source projects in Maharashtra. The MoU envisages the development of four PSPs aggregating 7,350 MW capacity, namely, Kalu 1,150 MW, Savitri 2,250 MW, Jalond 2,400 MW and Kengadi 1,550 MW (MoP, 2023b).

The Madhya Pradesh Government has laid down the foundation stone of the 1,440 MW PSP project in Neemuch District during October 2023, Greenko Group will be developing this project in Khemla village, Rampura tehsil, Neemuch District, with an investment of around Rs 100 billion and will be operational by June 2025. Later, it is proposed that the capacity of this project will be increased up to 1,920 MW. This will be among the India's largest PSP projects. The project will be able to integrate over 7,000 MW of RE capacity (MP GOV, 2024).

Table A6.1: PSP Projects Undertaken By Various Agencies For Development During Recent Times

Agreement between	State	Investment	Particulars/ Date/ PSP projects
Tata Power & Maharashtra Government	Maharashtra	US$ 1.56 billion	MOU Aug. 2023 Shirawta (1,800 MW) and Bhivpuri (1,000 MW) PSP
NHPC & Gujarat Power Corporation Limited	Gujarat	Rs. 4,000 Crore	MOU January 2024 Kuppa (750 MW) PSP
NHPC and Andhra Pradesh Power Generation Corporation Limited	Andhra Pradesh		MOU Aug. 2023 Kamlapadu (950 MW) and Yaganti (1,000 MW) PSP
NHPC and the Department of Energy of the Maharashtra government	Maharashtra		MOU June 2023 Development of Kalu 1,150 MW, Savitri 2,250 MW, Jalond 2,400 MW and Kengadi 1,550 MW PSPs

Agreement between	State	Investment	Particulars/ Date/ PSP projects
Greenko Group & Madhya Pradesh Government	Madhya Pradesh	Rs. Rs 100 billion	October 2023 to develop PSP 1,400 MW capacity in Neemuch district
JSW Neo Energy Limitedin & Uttrakhand Govt.	Uttrakhand		MOU Oct. 2023, To develop 2 PSP of 1,500 MW each
Torrent Power Limited & Maharaashtra Goveernment	Maharashtra	Rs 270 billion	MOU June 2023 To develop 3 PSP Karjat (3,000 MW), Maval (1,200 MW) and Junnar (1,500 MW)
Power Company of Karnataka Limited (PCKL) awarded contracts to JSW Neo Energy	Karnataka	Rs.14.75 million	Purchase agreement valid for 40 Yrs. 1 GW of electricity of eight hours per day from PSP continuous five-hour discharge. JSW Neo Energy won 300 MW Greenko got the balance 700 MW by quoting
Power Company of Karnataka Limited (PCKL) awarded contracts to Greenko KA 01 IREP	Karnataka	Rs 14.76 million	
Adani Green Energy Limited & Andhra Pradesh Govt.	Andhra Pradesh	Rs 239.85 billion	Dec. 2022 Development of Pedakota (1,000 MW) and Raiwada (600 MW)
Shirdi Sai Electricals Limited & Andhra Pradesh Govt.	Andhra Pradesh	Rs 88.55 billion	To Develop Yerravaram (1,200 MW) and Somasila (900 MW) PSP

Source: Burdett (2024), MoP (2024), MoP (2023a), MoP (2023b), MP Gov. (2024), Renewable Watch (2023), Torrent Power (2023), MercomIndia (2023), Power Line (2024

Besides, the Uttarakhand Government also entered into a MoU valued at Rs 150 billion with JSW Neo Energy Limited in October 2023 to establish two PSP projects in Almora District, each with a capacity of 1,500 MW. The proposed scheme entails the creation of a lower dam/reservoir at a distance of 8-10 km from the Kosi River at Site 1 in Joskote village, Almora, and an upper reservoir at Site 2 in Kurchaun village, Almora, situated approximately 16 km away from the Kosi River. The project will be developed over the course of the next five to six years (Renewable Watch, 2023).

Earlier, in June 2023, Torrent Power Limited has signed an MoU with the Maharashtra Government for the development of three PSPs of 5,700 MW capacity in the state. The projects would be executed at three sites identified by Torrent – Karjat (3,000 MW) in Raigarh District, Maval (1,200 MW) and Junnar (1,500 MW) in Pune District. All the sites are off-stream and these projects are planned to provide a minimum of six hours of energy storage on a daily basis. The projects would entail an investment of about Rs 270 billion. Torrent intends to execute these projects over a period of five years (Torrent Power, 2023).

In March 2023, Power Company of Karnataka Limited (PCKL) awarded contracts to JSW Neo Energy and Greenko KA 01 IREP for providing 1 GW of electricity of eight hours per day from PSP projects that offer continuous five-hour discharge. JSW Neo Energy won 300 MW by quoting Rs 14.75 million, while Greenko got the balance 700 MW by quoting Rs 14.76 million. The bidders will sign PPA with PCKL that are valid for 40 years (MercomIndia, 2023). Further, in December 2022, the Andhra Pradesh State Investment Promotion Board approved investments worth Rs 239.85 billion for the development of PSPs. Adani Green Energy Limited will set up 1,600 MW of PSPs with an investment of Rs 63.3 billion. The company's plans include a 1,000 MW plant in Pedakota, Alluri Sitarama Raju District, and a 600 MW plant in Raiwada in Anakapalli and Vizianagaram Districts. Work on the project is expected to commence in December 2024, with project commissioning within four years. Further, Shirdi Sai Electricals Limited will set up 2,100 MW of PSPs with an investment of Rs 88.55 billion. The company will develop a 1,200 MW project at Yerravaram and a 900 MW project at Somasila. The work is expected to be completed in phases by December 2028. (Power Line, 2024)

References for Annexure 6

Burdett, M. (2024). Asia-Pacific leads pumped-storage renaissance. Hydropower & Dams Issue One, 2024: 72 - 77.

MercomIndia (2023) Read more: https://www.mercomindia.com/jsw-greenko-win-karnatakas-1-gw-pumped-storage-projects. (https://www.mercomindia.com/jsw-greenko-win-karnatakas-1-gw-pumped-storage-projects)

MoP (Ministry of Power, Government of India) (2023a) NHPC and APGENCO join hands for implementation of Pumped Storage Hydropower Projects and other Renewable Energy Projects in Andhra Pradesh. Posted On: 24 AUG 2023 6:16PM by PIB Delhi (https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1951760)

MoP (Ministry of Power, Government of India) (2024) NHPC signs MoU with GPCL, Govt. of Gujarat; to invest ~ Rs. 4,000 crores in proposed 750 MW Kuppa Pumped Hydro Storage Project. Posted On: 04 JAN 2024 7:45PM by PIB Delhi (https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1993217#:~:text=4%2C000%20crores%20in%20proposed%20750%20MW%20Kuppa%20Pumped%20Hydro%20Storage%20Project&text=Taking%20a%20step%20forward%20towards,Kuppa%20Pumped%20Hydro%20Storage%20Project)

MoP (Ministry of Power, Government of India) (2023b) NHPC inks MoU with Department of Energy, Govt. of Maharashtra for Pumped Storage Schemes and Other Renewable Energy Source Projects. Posted On: 07 JUN 2023 12:21PM by PIB Delhi. (https://pib.gov.in/PressReleasePage.aspx?PRID=1930391)

MP GOV (Madhya Pradesh Government) (2024) The Pump Storage Project Underway in Khimla, Neemuch Promises Significant Benefits for the Region

PowerLine (2024) Focus on Pumped Storage: Clean and balancing power to address intermittency of renewables.(https://powerline.net.in/2024/02/04/focus-on-pumped-storage-clean-and-balancing-power-to-address-intermittency-of-renewables/)

Renewable Watch (2023) Uttarakhand government signs Rs 150 billion MoU with JSW Neo Energy. (https://renewablewatch.in/2023/10/05/uttarakhand-government-signs-rs-150-billion-mou-with-jsw-neo-energy/)

Torrent Power (2023) Torrent signs MoU with Govt of Maharashtra for three Pumped Storage Hydro Projects of 5,700 MW capacity (https://www.torrentpower.com/pdf/investors/MR_20230627150339.pdf)