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CSTEP CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

Pricing Mechanism of Pumped-Hydro Storage in India

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Designed and edited by CSTEP

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Introduction

India is planning to install 450 GW[1] of renewable energy (RE) generation capacity by 2030. A major share of RE comes from solar and wind energy sources. These are highly intermittent sources of energy, and the generation of power from these cannot be accurately predicted. Moreover, power from these RE sources cannot be dispatched based on real-time demand.

This is where utility-scale energy storages, with the ability to manage grid-balancing issues, come in. Among these, pumped-hydro energy storage (PHES) is a mature technology. PHES not only generates electricity for supply but also stores it in the form of potential energy of water. It is operated with two water reservoirs at different altitudes. Both reservoirs are connected through a penstock (water supply pipeline) with a reversible turbine in the middle. When PHES is operated to generate power, the upper reservoir supplies water to the lower reservoir through the penstock and turbine system to generate electricity. To store energy, water is pumped to the upper reservoir again using the excess energy available in the grid and stored in the form of potential energy.

In India, around 63 sites have been identified so far for pumped storage schemes with a probable installed capacity of 96,530[2] MW. Even though 4,785 MW of capacity has been constructed, only 3,305 MW is operable. The remaining 1,480 MW of capacity is not working in the pumping mode at present because of the delay in the construction of tail pool dams and vibrational issues. Additionally, 1580 MW of PHES is under construction and 9730 MW is under proposal development.

Status of PHES in India[3]

3305 MW	1480 MW	1580 MW	9730 MW
Operational capacity	Non-operational capacity	Under construction	Proposal development

1 https://mnre.gov.in/img/documents/uploads/file_s-1601801731896.pdf
2 https://cea.nic.in/old/reports/circulars/2020/146.pdf
3 https://cea.nic.in/wp-content/uploads/hepr/2021/02/pump_storage-2.pdf

Multifunctional Role

PHES is able to support grid operation by offering services such as peak load shaving, energy arbitrage, load following, round-the-clock support, RE smoothing, and other ancillary services.

Multifunctional Role

Peak load shaving
PHES is effective in peak load management of the grid by storing energy in the off-peak hours and supplying it when the demand is high.

Seasonal storage
The intermittent RE generation varies seasonally; PHES has the ability to cater to the seasonal mismatches of RE generation and the load.

Energy arbitrage
PHES may prove economical in the daily energy arbitrage business as it buys energy during the off-peak hours when the price is less and sells it during the peak hours when the price is high.

RE smoothing
In the case of large-scale integration of intermittent RE sources into the grid, PHES helps smooth out the variability by storing energy in the form of hydro potential, which can then be used when the grid needs it, making RE integration stable.

Load following
PHES, with its fast ramping up/down capability, maintains the stability in the grid by taking care of the sudden changes in load.

Ancillary services
PHES provides voltage support to the grid by generating/ absorbing reactive power, maintains the grid frequency within the desired range, acts as a spinning reserve during generation failure or power shortage, and energises part of the grid or generation station during unplanned events or blackouts.

Need for a new pricing mechanism

As per the Central Electricity Regulatory Commission (CERC) tariff determination regulations 2019–2024[4], the tariff for a PHES project includes fixed cost and variable cost components. The fixed cost component, or capacity charge, is to recover the capital cost incurred on the plant on an annual basis such as plant and machinery, manpower, and administration cost. The variable cost component, or the energy charge, is used to recover the cost incurred during the operation of the plant. It is calculated at a flat rate of 20 paise per kWh of the total energy scheduled (in excess of the design energy[5]) plus 75% of the energy consumed in pumping from the lower reservoir to the upper reservoir.

The major drawback of the current pricing mechanism is that it does not take into account the grid flexibility aspects of PHES. To have a stable, secure, and reliable grid operation, it is important that grid frequency and voltage are maintained at desired levels and generation and load are kept in balance. However, because of the generic pricing mechanism, PHES is not able to leverage its usability to the full capacity. It is important to develop a pricing mechanism for each specific service that the PHES offers.

Another issue with the current pricing mechanism is that it considers PHES only as a generator, which needs to recover its cost by selling power at a determined tariff to the beneficiaries/consumers. However, PHES operates in such a way that it acts as both a generator and a consumer. When water is being pumped from the lower reservoir to the upper reservoir, the PHES draws power from the grid and acts as a consumer, whereas at the time of releasing water and generating energy, it acts as a generator. Therefore, there is a need for developing a differential pricing mechanism for PHES during its pumping and generating mode (or peak and off-peak operation).

[4] http://www.cercind.gov.in/2019/regulation/Tariff%20Regulations-2019.pdf
[5] Design Energy can be defined as the total quantum of energy generated by the PHES

Recommendations

Based on an analysis, the Center for Study of Science, Technology and Policy (CSTEP) recommends the following:

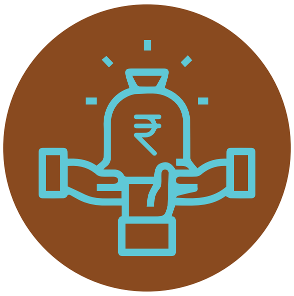
- **A differential pricing mechanism should be employed with different pumping and generation prices instead of having only generation-based energy charges.**
- **The profit generation from the differential pricing mechanism should be used for fixed cost recovery.**
- **Pricing mechanism for PHES should be based on specific use cases.**

A. For energy arbitrage/peak load shaving/load following use case of PHES *(Refer Annexure A.1)*:

- Operate PHES in the market as a merchant power plant with different pumping (off-peak rates) and generation prices (peak rates).
- The peak price should be 1.33-1.35 times the off-peak price for profit generation.
- Our analysis shows that there were 21 and 53 no-profit days in the year 2019 and 2020, respectively, for Tehri PHES in Uttarakhand.
- The profit of INR 157 crores (2019 market price) and INR 70 crores (2020 market price) of Tehri PHES yields a fixed cost recovery of 16% and 7%, respectively.
- If a PHES plant operating in the market has to provide grid flexibility, then there is a reduction in the overall profit earned by the plant.

B. For round-the-clock support and RE smoothing use case of PHES *(Refer Annexure A.2)*:

- One or a combination of the following incentives should be provided:
  - Compensation for avoiding RE curtailment.
  - Avoided cost from high-priced purchase of thermal or gas plants.
  - Grid flexibility incentive similar to ancillary unit plants.
  - Generation-based incentive in the range of INR 0–1 per unit to attract more investment in the sector.
- Our analysis shows that for the Pinnapuram PHES in Andhra Pradesh:
  - The profit generation ranges from INR 0.37 to INR 4.41 per unit.
  - The fixed cost recovery ranges from 10% to 122%.
  - If the price differential between pumping and generation price is INR 3.62 per unit there is 100% fixed cost recovery.



In addition to the above pricing mechanisms, we also recommend the following financing mechanisms[6] for total project cost funding:

- **Budgetary subsidy on viability gap funding (VGF)**: India has considerable experience with the VGF mechanism for large-scale RE projects. This should be extended towards PHES projects as well.
- **Expense distribution model** (resources, assets, and investment distribution) can be made feasible through collaboration between local government and developers. A public–private partnership (PPP) model can also be integrated with a similar concept. The utilisation of unused assets and infrastructure (such as open-pit coal mines and beneficiary-owned lands) will help reduce the risks associated with energy pricing and energy volume and provide stable cash flow.
- **Foreign direct investments (FDIs)**: Though the Government of India has approved 100% FDIs for development of the RE sector, there is no significant flow of funds for PHES. Government initiatives, such as the development of large-scale energy storage alongside RE, open up new opportunities for FDIs in the Indian PHES sector.

[6] Details of the funding mechanism is shown in Annexure B

Benefits

1. Higher revenue generation for PHES
2. Fixed cost recovery from the revenue earned
3. Competitive pricing for PHES by operating in the market
4. Attracting more investors in the PHES sector

Barriers

1. Delay in obtaining environmental clearances
2. Delay in construction
3. Delay in obtaining the approval of electricity regulatory commission for the new pricing mechanism

Annexure A: Differential Tariff Computation for PHES

In this section, we briefly discuss the new tariff computation methods for the use case of peak load shaving and RE smoothing.

A.1 Tariff computation for peak load shaving

In this tariff computation method, PHES is used as a merchant power plant in the market, i.e., they are operated in Indian power markets such as the Indian Energy Exchange (IEX) and Power Exchange of India Limited (PXIL). This methodology could also be employed for energy arbitrage and load following use cases. The primary input requirements are day-ahead real-time market prices, market buy and sell volume, and the load profile for the state. The dispatch strategy of PHES in the market can be in two ways:

- Pump during low prices and generate during high prices
- Pump during low prices and generate during peak load

Therefore, the energy cost of PHES is the weighted sum of the off-peak prices in the market depending on pumping requirements. The generation cost is the weighted sum of peak prices in the market depending upon generation requirements. The revenue earned by the PHES developer will be the price differential between peak and off-peak prices.

The method will be illustrated through the case study of Uttarakhand.

The state of Uttarakhand has the Tehri PHES to be commissioned by the year 2022. Uttarakhand belongs to the region of N2 in the IEX market. The Tehri PHES has a capacity of 1,000 MW with a round-trip efficiency of 80%. The annual generation and consumption of the plant will be 1,321.8 GWh and 1,651.6 GWh, respectively.

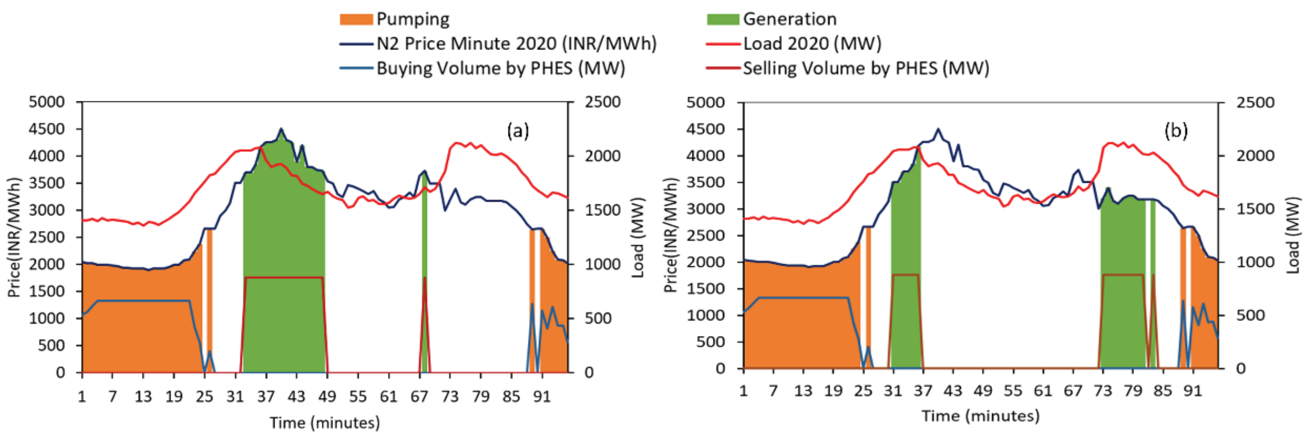


Figure 1: Dispatch plot of Tehri PHES—(a) maximising the profit (b) and peak load shaving

Figure 1 shows the dispatch plot of Tehri PHES for a day. Figure 1(a) shows maximising the profit scenario where the low-priced instances in the price minute curve is used for pumping and the high-priced instances are used for generation. Figure 1(b) shows the peak load shaving scenario where the low-priced instances are still used for pumping, whereas PHES generates during high peak load periods. The profit earned while operating PHES as shown in Figure 1(a) is INR 38,25,323 with an average peak tariff of INR 3.94 per kWh and an off-peak tariff of INR 2.15 per kWh. Similarly, the profit earned while operating PHES as shown in Figure 1(b) is INR 16,34,214 with an average peak tariff of INR 3.32 per kWh and an off-peak tariff of INR 2.15 per kWh. In both the cases, the Point of Connection (POC) charges, transmission losses, and IEX fees are considered. This clearly shows that if PHES systems need to be operated for peak load shaving in the market, they should be given some incentives.

Additionally, on some of the days, the price minute curves tend to remain invariable (minimal difference between high and low price instances in the price minute curve for a day), incurring loss to the PHES developer. To examine this price variability throughout the year, maximising the profit scenario was repeated for 2019 and 2020. The revenue for the different days are plotted in Figure 2. It is seen that on some of the days, PHES systems should not be operated as they will incur losses. The results are summarised in Table 2. The profit earned by the PHES system could be used for the recovery of capacity charges[7]. Hence, for the given profit, the fixed cost recovery will be 16% and 7% for 2019 and 2020 market prices, respectively.

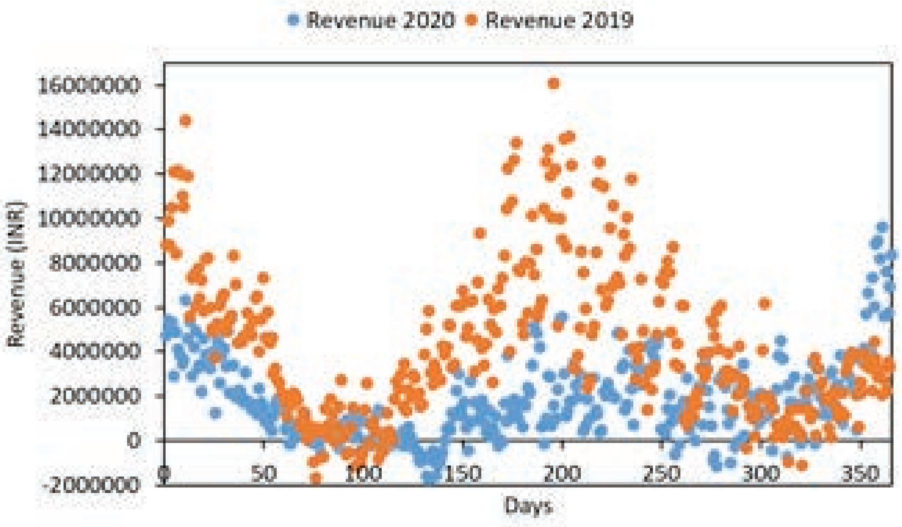


Figure 2: Revenue generation of PHES for all days when operated in the IEX market for 2019 and 2020

Table 2: Results for different days in the year when operated in the IEX market

Results	2019	2020
No profit generation days	21 days	53 days
Ratio of average peak price to off-peak price to generate profit	1.35	1.33
Max profit generated for a day (INR) Avg. peak price (INR per kWh) Off-peak price (INR per kWh)	1,60,82,247 (15 July) 7.5 2.25	96,14,821 (26 December) 5.3 1.95
Net profit for the year (INR crores)	157	70
Fixed cost recovery (%)	16	7

[7] Capacity charges are computed based on the CERC tariff regulations 2019-24

A.2. Tariff computation for RE smoothing

This tariff computation method can be utilised by grid-connected plants that utilise RE for their pumping requirements and by co-locating PHES plants with RE. This provision enables round-the-clock support from these RE plants. The input requirements are the RE profile (solar and wind profile) and load profile as seen by the PHES plant. The PHES plant utilises the excess RE available to charge and discharge during low RE and high load, thereby helping the RE plant to provide dispatchable power. It will also avoid the cost of RE curtailments and help the distribution companies (DISCOMs) to meet their Renewable Purchase Obligation (RPO) targets. The PHES plants can enter into long-term contracts or bilateral trade with DISCOMs.

The pumping cost of the PHES will be RE cost along with interconnection charges. The generation cost will include pumping price and certain incentives for providing grid flexibility. The incentives include the following:

i. Compensation for avoiding RE curtailment: The RE supply is curtailed from the grid in case of any transmission constraints, low system demand, or grid security issues. Since RE has been given “must-run” status, any curtailment has to be appropriately compensated. Since PHES would help reduce RE curtailment by using excess RE for pumping, we have considered the same compensation as an incentive for PHES. The different levels of compensation are shown in Table 3.

Table 3: RE curtailment penalty scenarios[8]

RE curtailment penalty scenarios	Compensation
Grid security reasons	0
Low system demand	50 paise per kWh
Transmission constraints (up to 7% curtailment)	Up to 50% of curtailed energy at the contracted price
Transmission constraints (beyond 7% curtailment)	50% of curtailed energy at the contracted price

ii. Avoided cost from high-priced purchase of power from thermal or gas plants: A PHES integrated RE plant would be able to supply firm, reliable, round-the-clock power supply. This would help DISCOMs avoid the cost of power purchase from high-priced thermal power plants. This avoided cost could be used to incentivise PHES.

iii. Grid flexibility compensation: PHES would be able to mitigate challenges associated with the intermittent and variable nature of RE, thus providing grid flexibility. The service offered needs to be compensated through the grid flexibility incentive. We have considered 50 paise per unit incentive provided to ancillary services for offering grid flexibility

iv. Generation-based incentive (GBI): This can attract more investment into the sector. We have considered a minimum and maximum value of INR 0 and 1 per unit, respectively.

The profit or loss earned by the PHES developer will be determined by these incentives.

This tariff computation method is illustrated through the case study of the Pinnapuram Integrated Renewable Energy Storage Project (IRESP) in Andhra Pradesh. The site has plans

[8] https://cea.nic.in/wp-content/uploads/2020/04/Presentation_RE_Curtailment.pdf

to install a solar plant with a capacity of 2,000 MW, a wind plant of 400 MW, and a PHES plant of 1,000 MW. The annual generation and consumption of the plant will be 2,774 GWh and 3,645 GWh, respectively, with a round-trip efficiency of 76%. The dispatch strategy of this plant is shown in Figure 3.

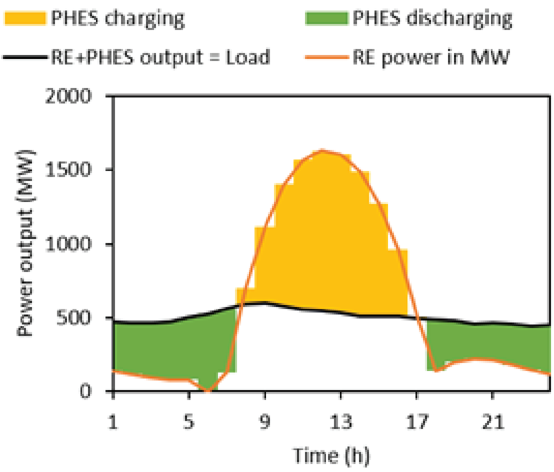


Figure 3: Dispatch strategy for Pinnapuram PHES Plant

Table 4 depicts the cost that DISCOMs would save by avoiding power purchase from thermal plants. We have analysed the specific case of Pinnapuram IRESP from the Andhra Pradesh tariff order. Therefore, for the case study, the maximum and the minimum deviations range between INR 0.37 and INR 0.91 per unit.

Table 4: Avoided cost from the purchase of power from high-priced thermal plants

Source	Energy (GWh)	Fixed cost (INR per unit)	Variable cost (INR per unit)	Total cost (INR per unit)	Deviation from NCE (INR per unit)
Andhra Pradesh Power Generation Corporation (APGENCO thermal)	7,104	1.54	3.39	4.93	0.37
Rayalaseema Thermal Power Plant (RTPP) stage IV	1,018	1.80	3.66	5.46	0.91
Dr Narla Tata Rao Thermal Power Station (NTTPS) V Stage V	1,467	1.80	3.14	4.94	0.39
Sri Damodaram Sanjeevaiah Thermal Power Station-I (SDSTPP-I)	6,565	2.00	3.14	5.14	0.59
Sri Damodaram Sanjeevaiah Thermal Power Station-II (SDSTPP-II)	1,621	1.80	3.14	4.94	0.39
Non-conventional energy (NCE)	14,097	0.00	4.55	4.55	0.00

The tariff computation for the Pinnapuram project based on the above method is shown in Table 5. We have shown the minimum and maximum scenarios as well as the three intermediate scenarios that could be applicable for the project. The minimum and maximum RE cost considered for the scenarios are INR 2 to 3 per unit. Similarly, an interconnection charge of INR 1 per unit is also assumed to the pumping cost. Hence, the profit earned by the Pinnapuram project will be in the range of INR 0.37 to INR 4.41 per unit with a capacity charge recovery of 10% to 122%, respectively.

Table 5: Tariff scenarios based on the analysis for Pinnapuram PHES project

		Minimum scenario	Intermediate scenario 1	Intermediate scenario 2	Intermediate scenario 3	Maximum scenario
Pumping cost (INR/kWh)	RE cost	2	2	2.5	2	3
	Interconnection charges	1	1	1	1	1
Profit/loss (INR/kWh)	Compensation for avoiding RE curtailment penalty	0	0.5	0.875*	1**	1.5
	Avoided cost from high-priced gas or thermal plants (from the AP tariff order)	0.37	0.37	0.37	0.91	0.91
	Grid flexibility incentive	0	0	0.5	0.5	1
	GBI	0	0.5	0.5	0.5	1
Generation cost (INR/kWh)		3.37	4.37	5.745	5.91	8.41

*5% RE curtailment

** 10% RE curtailment

Annexure B: PHES funding mechanism around the world

Around the world, PHES systems are capital-intensive power projects. Therefore, they require funding support through policy and regulations. To motivate the rapid increase in PHES capacity, countries having substantial PHES potential are providing various funding mechanisms to attract developers and investors towards this emerging energy storage sector.

Table 6: PHES funding mechanisms around the world

Country	Funding mechanisms
USA	Budgetary subsidy on the fixed cost part • Debt capital at low interest • Partnership • VGF
Australia	Expense distribution business model with multiple collaborators
China	Standard investment with 70:30 debt-equity ratio (generation-based incentive on tariff to promote competition between different PHES)
India	Standard investment with 70:30 debt-equity ratio

B.1 International Funding Mechanisms

USA has one of the largest shares of PHES with 22.6GW[9] installed capacity, making 14% of the global capacity. The US Government provides loans to developers through the Department of Energy (DoE) for increasing the PHES capacity. Funding of $40billion[10] has been released for all RE projects under three major funding schemes: debt capital at low interest, partnership, and flexible financing options such as VGF[11],[12]. This makes PHES projects more viable while keeping the PHES tariff competitive in the market price. Additionally, the Water Power Technologies Office (WPTO) under the Department of Energy also provides funds for research projects associated with PHES, targeting to increase the commercial viability of the PHES power sector.

Australia is also an emerging market for PHES. It has adopted the expense distribution model as one of the potential funding methods for numerous PHES projects. Expense distribution is not limited to the sharing of capital investment; it also includes assets distribution. It is a concept based on collaborative ownership and funding. Multiple partners including private and government stakeholders can own the required investment, resources, and assets. Based on the value of the contribution, benefits from PHES are shared. These kinds of PHES projects are usually bundled with RE power generation in the same region. It leads to avoiding extra utility charges and reduced technical losses and hence reduced funding requirements for operational costs[13],[14].

9 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf
10 https://www.energy.gov/lpo/loan-programs-office
11 https://www.energy.gov/sites/prod/files/2020/07/f76/PSH_FAST_Commissioning_Technical_Report_ORNL.pdf
12 https://www.osti.gov/biblio/1372397
13 https://arena.gov.au/assets/2020/10/cultana-pumped-hydro-energy-storage-project-phase-2.pdf
14 https://bit.ly/3shJeNR

China has the world's largest PHES capacity of 32 GW[15] (21% of global capacity). Developers usually go with the conventional 70:30 debt-equity ratios for developing these projects. Having significant storage capacity, China is promoting competition between the existing PHES through generation-based incentives (GBI)[16]. This tariff mechanism provides additional subsidy on a per-unit generation basis with respect to the national average utilisation hours of PHES plants in the country. If a PHES plant generates more energy, its per unit price of subsidy also increases. This leads to a reduction in the generation tariff, increased competition, and high PHES utilisation.

B.2. Indian Context

India's 4.78 GW of total installed PHES capacity has been set up using the conventional funding method of 70:30 debt-equity ratio, where debt is taken as long-term loans from banks or other funding organisations on a fixed interest rate. Generally, this funding method works well for other conventional and renewable power plants. However, the capital cost required along with the operational cost of PHES is substantially high in India. International funding was secured from the International Cooperation Agency (JICA) and Overseas Economic Cooperation Fund (OECF) of Japan. Funding has been provided for the 900 MW Purulia Pumped Storage Project in West Bengal and the 250 MW Ghatghar PHES plant in Maharashtra. Considering the international best practices of experienced countries, the adoption of some specific funding mechanisms shall be beneficial for Indian PHES projects.

[15] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf
[16] https://www.e3s-conferences.org/articles/e3sconf/pdf/2018/13/e3sconf_icemee2018_04016.pdf

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