Pumped Storage Development as a National Strategy for Long Term Energy Storage to meet Net Zero Emissions Target for India

WORLD ENERGY COUNCIL INDIA

Contents

Abbreviations 5
Context 7
Foreword 8
Executive Summary 9
1. Introduction 11
1.1. Current global energy scenario 12
1.2. Clean energy transition in India 14
1.3. PSH scenario and role in clean energy transition 15
1.4. PSH scenario across the world 16
1.5. PSH in India 18
1.6. PHS capacity status 19
1.7. State level activity 20
1.8. Future outlook of PSH in India as per CEA 21
2. Indian Energy Scenarios 22
2.1. Objectives 23
2.2. Assumptions 23
2.3. Methodology - approach to project the future energy scenario of India 24
2.4. Results - Energy supply mix 2030, 2040, 2050 & 2060 (high RE scenario vs high hydro) 27
2.5. Results - Electricity Generation as per the mix (High RE Scenario vs High Hydro) 29
2.6. Results – Installed Capacity as per the mix (High RE Scenario vs High Hydro) 31
2.7. Residual demand curve is reflection of flexibility estimation 33
2.8. Flexibility Requirements Estimation – Flow chart 36
2.9. Residual demand curve: High RE Scenario – A Day in 2030 (GW) 36
2.10. Residual demand curve: High RE Scenario – A Day in 2040 37
2.11. Residual demand curve: High RE Scenario – A Day in 2050 37
2.11.1. Approach for the storage estimation calculations 38
2.12. Results: Flexibility Requirement in high RE scenario (2030, 2040 & 2050) 39
2.13. Comparison of values for storage estimations 40
2.14. Trends pushing for energy storage 41
2.15. Need of flexibility is a demand factor for storage technology 42
2.16. Future needs of Energy Storage 44
3. Techno-Commercial analysis of storage technology 45
3.1. Types of Storage Technologies 46
3.2. Applications and Maturity of Storage Technology 46
3.3. Economic Evaluation of Alternate Energy Storage Options 47
3.4. Levelized Generation Cost of Storage Technology 49
3.5. Comparative Life Cycle Analysis (LCA) of various Storage technologies 52
4. Identification of PSH projects 55
4.1. Identification of specific large scale PSP schemes 56
4.2. Identification of PSPs for Flexible/ RTC/ Peak Hour Supply 64
5. Barriers & Challenges 67
5.1. Revamping the project allotment process 68
5.2. Barriers & Challenges impacting PSP development and their mitigation 69
5.2.1. Delays in approvals and clearances 69
5.2.2. Land Acquisition and R&R - I 69
5.2.3. Project Financing – I 71
5.2.4. Financial and Fiscal Incentives for PSPs to ensure commercial viability 73
5.2.5. Development of a Techno - Commercial Business Model – regulated market 74
5.4 Policy & Regulatory Level 76
5.3.1. Differentiated tariff structure 76
5.3.2. Tariff Optimization Models for bundling of Pumped Storage & Renewable Energy 76
5.3.3. Other interventions 78
6. Conclusion 79

List of Tables

Table 1: Likely installed PHS capacity by 2029-30 (MW) 21
Table 2: Energy supply mix (High RE) % 27
Table 3: Energy supply mix (High hydro) % 27
Table 4: Generation as per mix (High RE) TWh 29
Table 5: Generation as per mix (high hydro) TWh 29
Table 6: IC as per mix (High RE) GW 31
Table 7: IC as per mix (high hydro) GW 31
Table 8: EV demand analysis 34
Table 9: Flexibility Requirement in high RE scenario (2030, 2040 & 2050) 39
Table 10: Comparison of values for storage estimation 40
Table 11: Maturity and application of various technology 46
Table 12: Economic evaluation of various storage technology 47
Table 13: Comparison of different storage technology 47
Table 14: Project details 49
Table 15: LCOE_PSP - assumptions and results 49
Table 16: LCOE_BESS - assumptions and results 50
Table 17: Comparison of BESS Tenders 51
Table 18: Comparative analysis - PSP vs BESS 54
Table 19: Working in Pumping model 56
Table 20: Presently not working in Pumping mode 56
Table 21: Under active construction and on which construction is held up 57
Table 22: Both reservoirs existing 57
Table 23: One reservoir existing & one to be constructed 58
Table 24: Both reservoirs to be constructed 59
Table 25: PFR prepared 60
Table 26: Under Preparation 60
Table 27: Indication of identified PSP sites to NHPC 61
Table 28: Identification of specific large scale PSP schemes – Pursued by NHPC (JV basis) 62
Table 29: Indication of identified PSP sites to THDCIL 62
Table 30: Indication of identified PSP sites to SJVNL 62
Table 31: Indication of identified PSP sites to NEEPCO 63
Table 32: Indication of identified PSP sites to DVC 63
Table 33: Indication of identified PSP sites to BBMB 63
Table 34: Tax free bonds vs tax saving bonds 72
Table 35: Constructs of techno – commercial business model for regulated market structure 75
Table 36: Constructs of techno – commercial business model for liberalized market structure 75

List of Figures

Figure 1: Primary energy mix 2020 12
Figure 2: All India Installed capacity (GW)........ 12
Figure 3: PSH illustration 15
Figure 4: Net hydropower capacity additions (2021-30) 16
Figure 5: Country-wise PHS IC (GW) as on 2020........ 16
Figure 6: State-wise PSP potential (MW) 18
Figure 7: Region-wise PSP potential........ 18
Figure 8: PHS capacity status MW 19
Figure 9: State level activity 20
Figure 10: Likely installed capacity (MW) 2029-30........ 21
Figure 11: Supply mix (high RE) %........ 28
Figure 12: Supply Mix (High hydro) %........ 28
Figure 13: Generation Mix (high hydro) TWh........ 30
Figure 14: Generation Mix (High RE) TWh........ 30
Figure 15: IC (high RE) GW..... 32
Figure 16: IC (high hydro) GW 32
Figure 17: Hourly demand curve- A Day in Jan 2020........ 33
Figure 18: EV Charging pattern in a day........ 33
Figure 19: Demand Curve - Day in Jan 2030 34
Figure 20: Demand curve: A day in Jan 2040 (GW) 35
Figure 21: Demand curve: A day in Jan 2050 (GW) 35
Figure 22: Residual demand curve: High RE Scenario – A Day in 2030 (GW)........36
Figure 23: Residual demand curve: High RE Scenario – A Day in 2040 37
Figure 24: Residual demand curve: High RE Scenario – A Day in 2050 37
Figure 25: Future needs of Energy Storage........ 44
Figure 26: Types of Storage Technologies 46
Figure 27: Life cycle impacts of storage technologies........ 52
Figure 28: Tamil Nadu wind gen vs solar gen vs Kadamparai gen / pump MW (19-8-19)........ 65
Figure 29: Tamil Nadu wind gen vs solar gen vs Kadamparai gen / pump MW (15-8-16)........ 65
Figure 30: Peak power support from ghatghar PSP 66
Figure 31: Comparison of deviation (operation vs GAMS optimization) 67

Abbreviations

APGCL	Assam Power Generation Corporation
BOOT	Build, own, operate, transfer
BU	Billion Units
BVPCL	Beas Valley Power Corporation Limited
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation, and storage
CEA	Central Electricity Authority of India
CERC	Central Electricity Regulatory Commission
CoP	Conference of the Parties
CPSE	Central Public Sector Enterprises
CSR	Corporate Social Responsibility
CUF	Capacity Utilisation Factor
CVPPL	Chenab Valley Power Projects
DAM	Day-ahead Market
DBFOO	Design build, finance, own, operate
DPR	Detailed Project Report
DSRA	Debt Service Reserve Account
EPC	Engineering, Procurement and Construction
ESG	Environmental, Social, and Governance
EV	Electric Vehicles
FAME	Faster Adoption and Manufacturing of Electric Vehicles
FOO	Finance owns operate
FRA	Forest Rights Act
GHG	Green House Gases
GoI	Government of India
GST	Goods and Service Tax
GTAM	Green Term-Ahead Market
GW	Gigawatt
GWh	Gigawatt hour
HPP	Hydro Power Projects
IBN	Investment Board of Nepal
IC	Installed Capacity
IDC	Interest during construction
IPP	Independent power producer
JKSPDC	Jammu & Kashmir State Power Development Corporation
KPI	Key Performance Indicators
KSEB	Kerala State Electricity Board Limited
kWh	Kilowatt hour
LADF	Local Area Development Fund
MIT	Massachusetts Institute of Technology
MOA	Memorandum of Association
MoU	Memorandum of understanding
MU	Million Units
MW	Megawatt
NECP	National Energy and Climate Plan

NEEPCO	North-eastern Electric Power Corporation Limited
NITI	National Institution for Transforming India
NREL	National Renewable Energy Laboratory
PCF	Pan-Canadian Framework
PLF	Plant load factor
PLR	Prime Lending Rate
PPA	Power Purchase Agreements
PSU	Public Sector Undertaking
PV	Photovoltaic
R&R	Resettlement & Rehabilitation
RE	Renewable Energy
S&I	Survey and Investigation
SJVN	Satluj Jal Vidyut Nigam Limited
SMR	Small modular reactors
SPV	Special purpose vehicle
T&D	Transmission and Distribution Losses
THDC	Tehri Hydro Development Corporation Limited
TPCL	Tata Power Company, Ltd.
TWh	Terawatt hour
UJVNL	Uttarakhand Jal Vidyut Nigam Ltd
WEF	World Economic Forum

Context

The India Member Committee of the World Energy Council aims to be the foremost energy think-tank of the country and the voice of the sector. The organization is truly representative of the Indian energy sector and contributes to advancing the energy goals of India. Its mission is to facilitate review, research, and advocacy of energy technology, policy, and strategy; to provide a platform for dialogue within the Indian energy sector; and to collaborate with member committees worldwide towards long term sustainable supply and use of energy. The India Member Committee brings together high-level players in the energy sector together to forge a better understanding of energy issues towards identifying and implementing sustainable, effective solutions.

Following are the two objectives of the Study:

1. **Road Map and Policy Interventions & Key Drivers to accelerate development of mid-size (Up to 200-500 MW) Hydro Power Projects in India by 2050.**
2. **Pumped Storage Development as a National Strategy for Long Term Energy Storage to meet net Zero Emissions Target for India.**

For each of these study, stakeholder consultation has been conducted with developers (public/private), operators, lenders, states, CEA, regulators etc. in detailed manner, Indian energy scenarios including generation mix of 2030, 2040,2050 has been projected via developing a model along with projected share of hydropower in overall Indian energy scenarios and thorough secondary research has been done as per the scope of work as stipulated.

This is the detailed report on the second objective of the study i.e., “Pumped Storage Development as a National Strategy for Long Term Energy Storage to meet net Zero Emissions Target for India”.

The Overview of strategic areas of the projects scope are:

Energy Transition outlook in India

- Deliver global views on energy transition and electricity sector megatrends as a comparison, with deep dive in the Indian context and local conditions.
- Energy Scenario projections up to 2030, 2040 & 2050.

Challenges faced & key measures

- Identifying impediments in project implementation.
- Interventions required to accelerate project development.
- Assessment of specific project for implementation.

Creating new Market Design

- Gather insights on current practices
- Deep dive on the key areas of improvement.
- High level views on efficient market designs and industry megatrends .

Policy Advocacy

- Monitoring the target vs achievement statistics every quarter based on growth targets.
- Devising strategies to implement progressive policies and regulations.

Foreword

The report is prepared by Ernst and Young LLP for World Energy Council India on the topic "Pumped Storage Development as a National Strategy for Long Term Energy Storage to meet net Zero Emissions Target for India". The period between 2022 and 2050 is critical for Indian energy sector owing to two reasons. First, Indian energy sector is preparing a trajectory to achieve net zero emissions by 2070. Second, India will also witness a high electricity demand owing to its promising economic growth. For striking a balance between the two, role of pumped hydro project is quite important. Though, India has a hydro power potential of ~96 GW, not even 1/10th of the total potential has been tapped so far. However, number of projects have taken off recently. Unlike battery storage technology that uses expensive and critical materials such as lithium, nickel, and cobalt (lithium-based), or polluting materials such as lead, Pumped hydro storage(PHS) uses the potential energy of water as the storage medium. Also, batteries have a much shorter lifespan, making their replacement and disposal a environmental concern. Thus, 'PHS' is best suited for complementing India's storage needs.

Considering the strategic nature of the subject, views of multiple stakeholders have been collected. These include various wings of CEA, CERC, CWC, Grid Controller of India (formerly POSOCO), NHPC, SJVN, THDC, NTPC hydro units, IPPs, banks and financial institutions, equity funds, discoms etc. Therefore, we are expressing our gratitude to the respected officials and management of these organizations. We also want to express our thanks to the experts – Shri Anil Kumar Jha and Shri Janardan Choudhary for critically examining the report at various stages and providing their valuable insights. Last but not the least , we would like to thank World Energy Council India for giving an opportunity to work on the project. Working with such diversified stakeholder pool enabled us to capture most of the issues and proposed workable solution.

Executive Summary

India has set a noble yet ambitious target to achieve net zero GHG emissions as a long-term goal. This will require our country to speed up deployment of cleaner sources of electricity generation such as wind and solar, which will lead to greater grid variabilities. This study suggests that India will need a minimum of 50.7 GWh of storage by 2030, 1300 GWh by 2040 and 4097 GWh by 2050. Out of the major options available pumped storage system emerges as a better option than battery energy storage systems for meeting the requirements of energy storage in Indian context. Advantages of PSH are lower life cycle cost, no dependency on imports, no need of preparing a safe disposal plan, lesser environmental impact and a lower levelized cost of energy storage. However, gestation period of PSH is high, the project construction needs to start early. In India only ~3 GW is working in pumping mode out of a total potential of 96.5 GW in 63 identified sites. To realize its potential of some of the key interventions are summarized below:

- **Revamping project allotment process:** The state should clearly define the project allotment process to CPSU, state sector PSU and IPPs. State government should ideally follow the competitive bidding route for allocating the project. For conducting competitive bidding, a standard bidding document may be developed which may be adopted by different states. The bidding criteria should not be free power (since it is not energy generation source but an energy storage device) but tariff or VGF. State shall have the option to allot project on MOU basis. Also, the SOP, application format and allocation criteria for allotting the project on MOU basis should be notified by various states. The MOA/allotment agreement may need to homogeneous and concessions to state government shouldn't have a bearing on tariff. Moreover, the MOA/allotment agreement should clearly define the milestones. and the outcome of not meeting the milestones.
- **Expediting clearances:** There is scope of introducing methods which will crash the time schedule. Such interventions include submission of online form based DPR, defining maximum turnaround time for every process and sub process, and introducing one stop window for getting clearances.
- **Increasing the involvement of state government:** Participation of state government in the entire process needs to be increased. State government should play an active role in organizing public hearings, conducting awareness outreach program, acquiring land, preparing, and executing a SOP based law and order maintaining program etc.
- **Concessions for reducing tariff:** Required concessions from state and central government may also be given to reduce the tariff. This will improve the saleability of power and increase the viability of the plant. Some of these concessions include partial/full CGST and SGST waiver (alternatively applicable GST rates may be brought to the level as applicable for solar projects), including the dedicated transmission line under enabling infrastructure, waiver of upfront premium, waiver of GST on royalty and cess, if any. State should also consider waiver of water cess (if at all water cess be applicable the same shall be charged on one time drawl of water and on an annual makeup/losses in the pondage system) and state specific tax. Waiver of ISTS charges, similar to renewable, may also makes pumped hydro station further lucrative.
- **No free power:** Since, it's not an energy generation source but an energy storage device, therefore free power and LADF should not be applicable in this case. Unlike hydro power generation project there is input cost i.e., cost of electricity for pumping (charging the storage system).

- **Increasing the availability of capital:** Lenders may be given tax concessions on the interest charged (till certain rate say MCLR plus 50 bps) against the loan disbursed for the development of hydro power projects. This will act as an incentive for funding hydro power projects. The sector cap may also be relaxed for funding hydro power projects/PHS.
- **Development of ancillary services market:** Ancillary Market is currently maturing in India. The recent (Ancillary Services) Regulations, 2022, published by CERC proposes to introduce marketbased procurement of tertiary and secondary reserves ancillary services. Introduction of additional services (such as remuneration mechanisms for black start services, reactive services, etc.) – as sub-segments – within the ambit of existing services would give more opportunity to hydropower plants to utilize their capabilities like fast ramp-up and ramp-down, start-up and shut-down etc. on the Market Platforms like IEX, PXIL, HPEX etc.
- **Remuneration mechanism:** Remuneration mechanism for storage solutions including PHS needs to be aptly devised. There are multiple attempts to value the ancillary services based on multipliers available in developed markets such as US. However, such multipliers may not be used in Indian context as such markets are co-optimized and ancillary services solutions are earning in more than one markets. However, Indian power market is yet to achieve the required depth. Therefore, appropriate compensation mechanism may be devised for procuring storage capacity which may give appropriate market signals and developers shall be motivated towards developing capacity. Conducting auctions to procure storage capacity (similar to SECI 500MW BESS capacity) may be replicated for pumped storage projects also.

Chapter 1

Introduction

1.1. Current global energy scenario

Conventional sources are still in dominance which is expected to change because of push towards clean energy transition. Below graph shows the global energy mix (2020): -

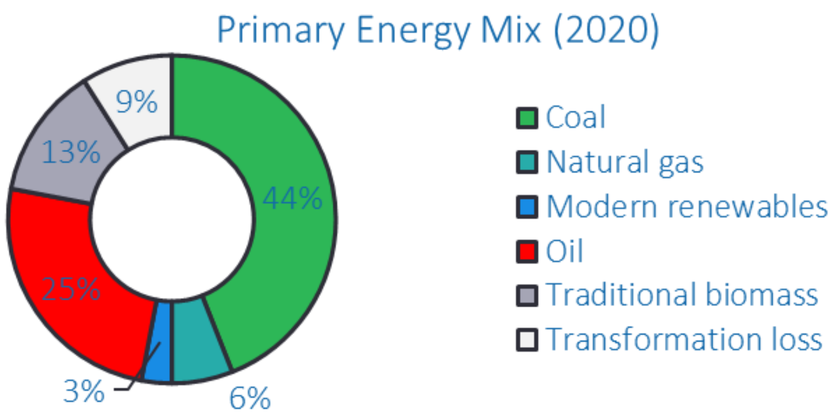


Figure 1:Primary energy mix 2020[1]

World is still dependent upon traditional fossil-based resources

- As per IEA's 'India Energy Outlook 2021', the primary energy mix is currently dominated by coal and oil contributing ~44% and ~25% respectively in 2020.
- Modern renewables contribute only ~3% of overall primary energy demand in the present scenario.

Current Indian energy scenario

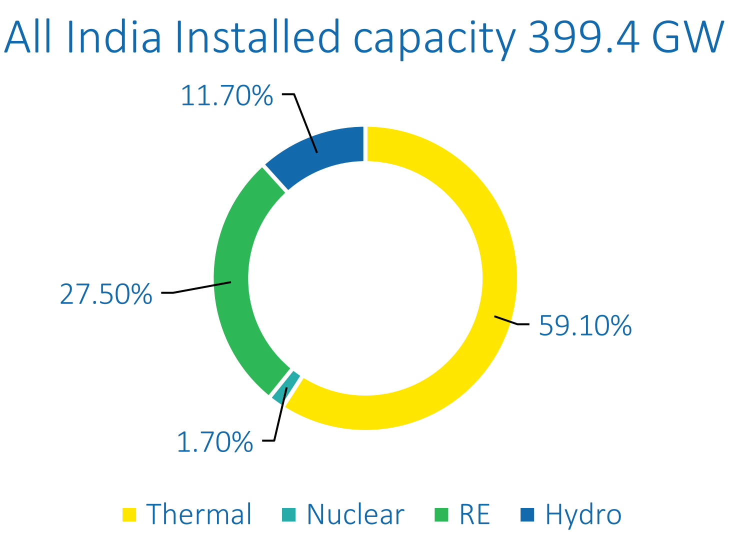


Figure 2: All India Installed capacity (GW)[2]

1 – IEA 2021

2 – CEA report (Data is as on 31.03.2022), IEA 2021

India has a coal dominated power system with 51% share (204 GW) in the installed capacity as of Mar 2022 (% of Installed Capacity)

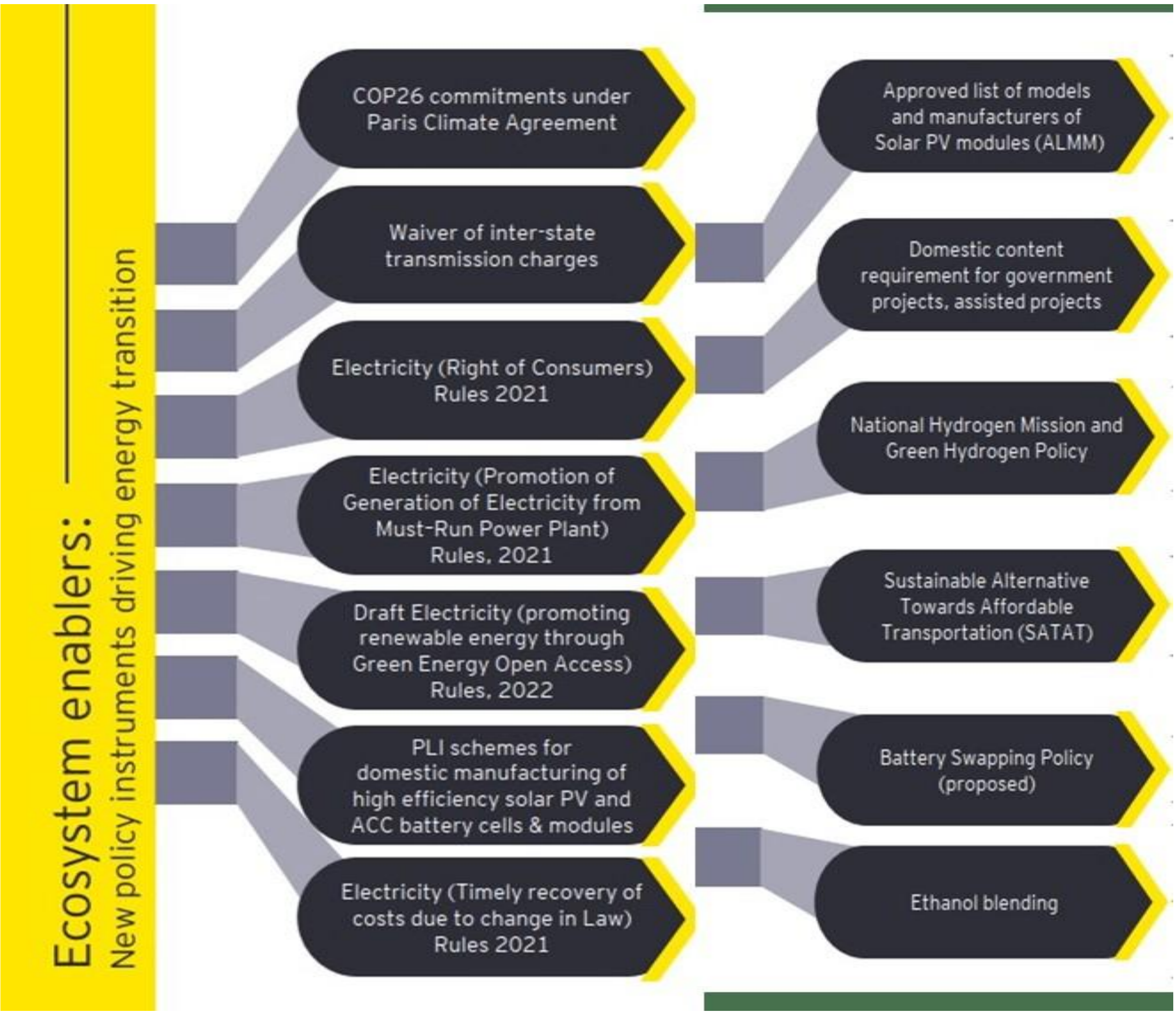
- India's installed capacity (Mar 2022) consists of 59.1% of thermal; 11.7% of hydro; 1.7% of nuclear and 27.5% of renewable energy (RE). It shows the domination of thermal in India's generation mix.
- India's per capita energy consumption and emissions is less than half of global average in the present scenario. This is expected to rise substantially with rapid economic development as more people in the low-income category is lifted out of poverty.
- Further, India's CO2 emissions has been increasing rapidly from 0.98 billion tons in the year 2000 to ~2.5 billion tons in 2019 as per IEA 2021.

For the sustainable development, **clean energy transition** needs to take the front stage. Hence, policy support is needed in the decoupling the economic development and emissions intensity of primary energy consumption. India is taking strides in the clean energy transition.

1.2. Clean energy transition in India

IEA Energy Outlook 2021 also predicts electricity growth propelled by renewable energy sources.

Ecosystem enablers: new policy instruments driving energy transition: -



India is already spearing towards clean energy transition

- As per IEA's 'India Energy Outlook 2021', in the more optimistic sustainable development scenario, total primary energy demand and total final consumption will see a modest growth of 7% and 13% respectively by 2030. Electricity demand will see a robust growth of 59% by 2030 in that scenario, largely driven by renewable energy sources.
- CO2 emissions from energy sector will contract by 4% indicating that energy related emissions may peak in this decade. Most importantly, the share of electricity in total final energy consumption is expected to rise to 24% as electrification of mobility and industrial applications (fossil fuel to electricity) gains further momentum.
- By 2030, Coal's dominance in primary energy mix will end with a modest share of 46%.

India in CoP - 26

India's updated Nationally Determined Contribution (NDC) has been communicated to the United Nations Framework Convention on Climate Change (UNFCCC) -

1. India now stands committed to reduce Emissions Intensity of its GDP by 45 percent by 2030, from 2005 level.
2. Achieve about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.

As per IEA, with the proliferation of clean energy technologies which are intermittent in nature, there will be an **increasing need of or system flexibility and storage** to facilitate the integration of larger shares of variable renewables drives. Amongst commercial storage systems available, one key option is **pumped storage hydropower (PSH).**

1.3. PSH scenario and role in clean energy transition

PSH support grid in ensuring its flexibility and the positive part is its expected strong capacity addition in the coming decade.

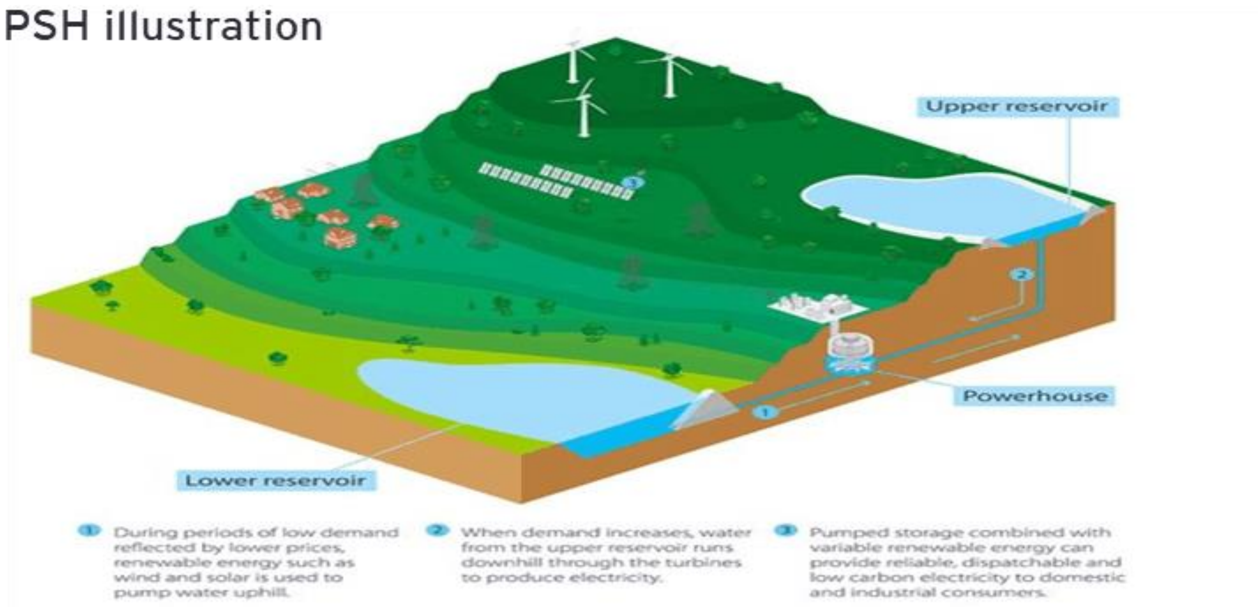


Figure 3: PSH illustration

- Pumped storage hydro plants serve the grid in wide range of applications and represent a valuable source of flexibility.
- It provides peak shaving, load balancing, frequency regulation, back-up reserve, spinning reserve, quick-start capability, black-start capability, and voltage support, etc.
- It provides very fast ramping up/down & peak/off-peak balancing support because of its inherent flexibility.

- PSH's flexibility, viz. fast ramp rates, fast start up and shutdown, low cycling costs, and accurate control make them ideal suppliers of regulation and contingency reserve ancillary services, and thus help in managing renewable energy grid integration.

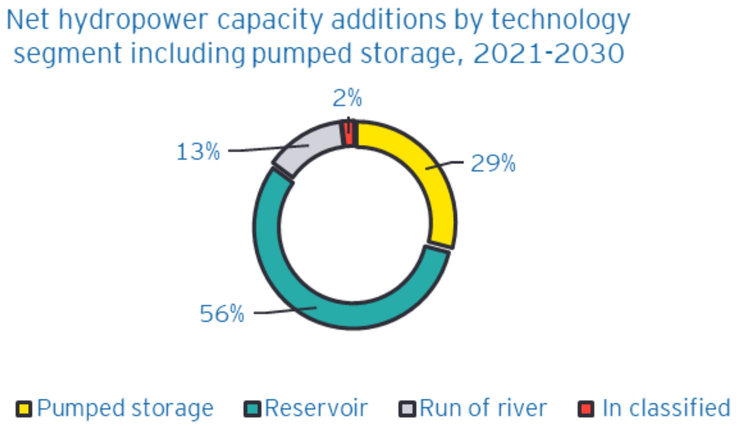


Figure 4: Net hydropower capacity additions (2021-30)[3]

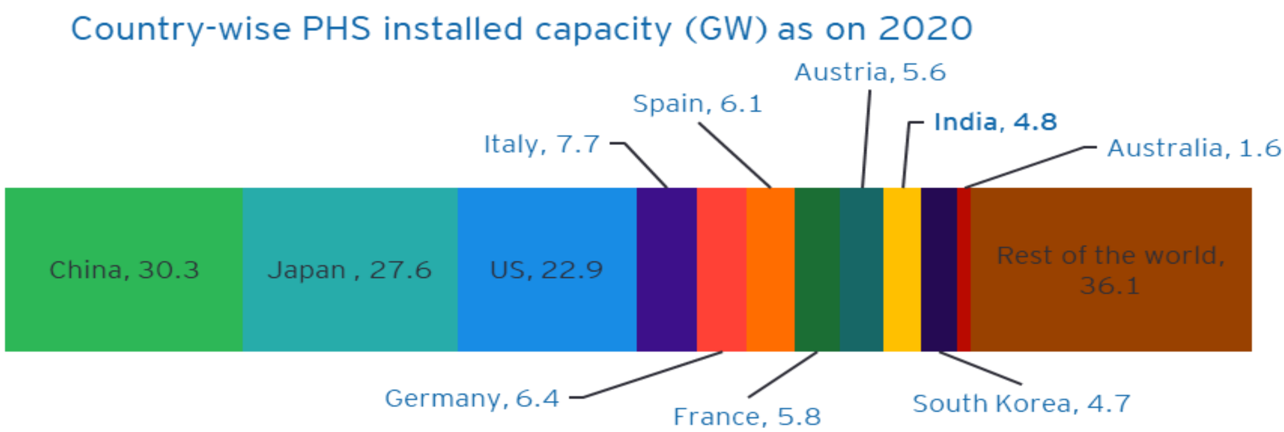
PSH global future scenario

- Due to flexibility and storage capability along with low operational costs and large storage capacities of PSH, it is well suited for supporting renewable energy integration in the grid.
- PSH is already providing 85% of world's total installed electricity storage capacity of 190 GW.
- With the capacity addition growth of 29% in the current decade, PSH is set to remain mainstay in the coming decade also. IEA forecast it to expand by 65 GW globally during 2021-30 which is highest ever decadal growth and doubled the growth rate of 34 GW during 1971-80.

IRENA has also forecasted that PSH needs to reach **325 GW** (double that current installed capacity of 158 GW) to **accommodate the global energy transition**

1.4. PSH scenario across the world

China is leading in terms of PSH installed capacity



Total - 158 GW

Figure 5: Country-wise PHS IC (GW) as on 2020[4]

3 – IEA 2020, Hydropower Special Market Report, 4 – IHA 2020 Hydropower Status Report

- International Hydropower Association estimate shows installed capacity of PSH as 158 GW with storing capacity up to 9,000 GWh.
- The potential areas for PSH development are - retrofitting disused mines, underground caverns, non-powered dams, and conventional hydro plants.

China

- Storage assets are considered as grid assets and are managed by state grid companies.
- 2-part tariff scheme is there. The capacity fee rewards the availability of the pumped hydro plant and the support services that it provides to the grid (power system reserve, frequency and voltage regulation, black start) and energy tariff compensates the variable operating costs such as pumping charges and generation losses.

Israel

- Israel Electricity Authority has fixed target of 800 MW of PSH (~5% of 18 GW installed capacity) with an objective to balance increasing solar and wind production.
- 20-year long duration PPA is signed with Independent Power Producer which builds plant.
- Revenue comes from three payments - basic availability payment, energy payment and performance payment.

Austria

- With a target of 100% renewable energy in 2030, hydropower is considered as a key enabler for energy transition.
- European Union has put in place public funding mechanisms such as the Projects of Common Interests (PCI). These are key infrastructure projects aimed at completing the European internal energy market to help the EU achieve its energy and climate policy objectives: delivering affordable, secure, and sustainable energy for all Europeans and contributing to a climate-neutral economy by 2050. PSH is also a part of it.

Source – CEA report titled "Status of Pumped Storage development in India as on 30.04.22, https://irade.org/Role%20of%20Pumped%20Hydro%20Energy%20Storage%20in%20Indias%20Renewable%20Transition-%20Final%20Report.pdf

1.5. PSH in India

India has a total PSH potential of 96.5 GW in 63 identified sites

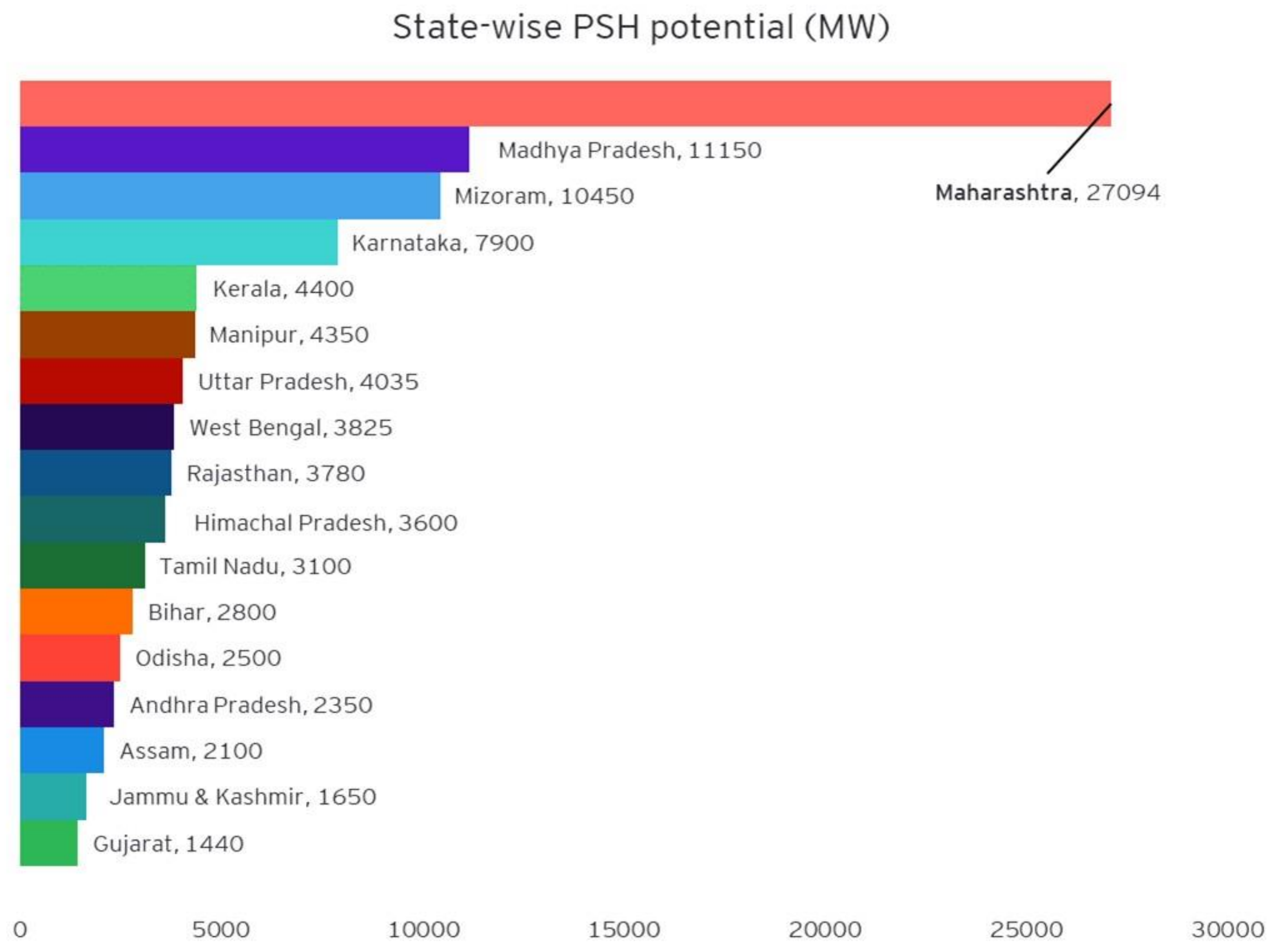


Figure 6: State-wise PSP potential (MW)[5]

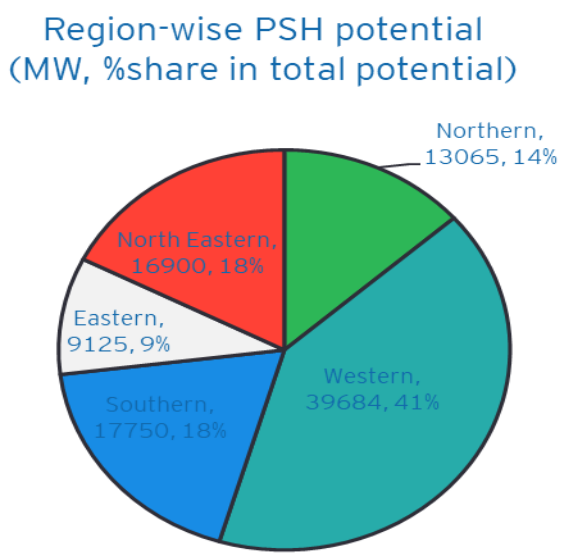


Figure 7: Region - wise PSP potential[5]

5 – https://www.keralaenergy.gov.in/files/pdf2018/presentations08_02_2018.pdf

- 96.5 GW potential is excluding the schemes that could be taken up on the existing reservoirs and the proposed schemes on small stream/Nallah.
- Maharashtra, Madhya Pradesh & Mizoram have the highest PSH potential and together capture 50.4% of the total potential.
- Western region has the highest potential with 41% share out of total potential.

1.6. PHS capacity status

Only ~3 GW is working in pumping mode out of total potential of 96.5 GW in India.

Below figure shows the PHS potential utilization in India (as on 30.04.22 (MW))

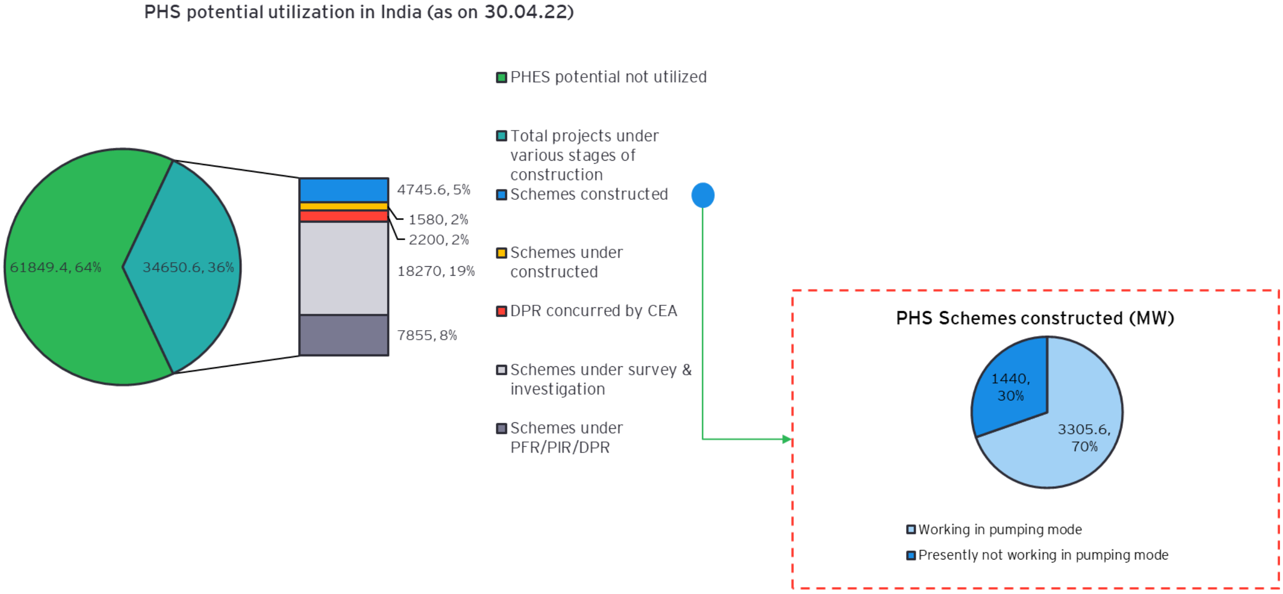


Figure 8: PHS capacity status MW[6]

- ~62 GW (64%) is the PHES potential which is not utilized till date.
- ~35 GW (36%) is the project capacity which are under different stages of execution.
- Out of 35 GW, ~26 GW (75%) of the capacity is lying at the stage of initial study which refers to project either under PFR/DPR preparation or under survey & investigation stage.
- Only 1.6 GW of the projects are at construction phase indicating less capacity addition in the coming future.

6 – CEA report titled "Status of Pumped Storage development in India as on 30.04.22, https://irade.org/Role%20of%20Pumped%20Hydro%20Energy%20Storage%20in%20Indias%20Renewable%20Transition-%20Final%20Report.pdf

1.7. State level activity

Andhra Pradesh & Maharashtra are the states leading in PSH project execution

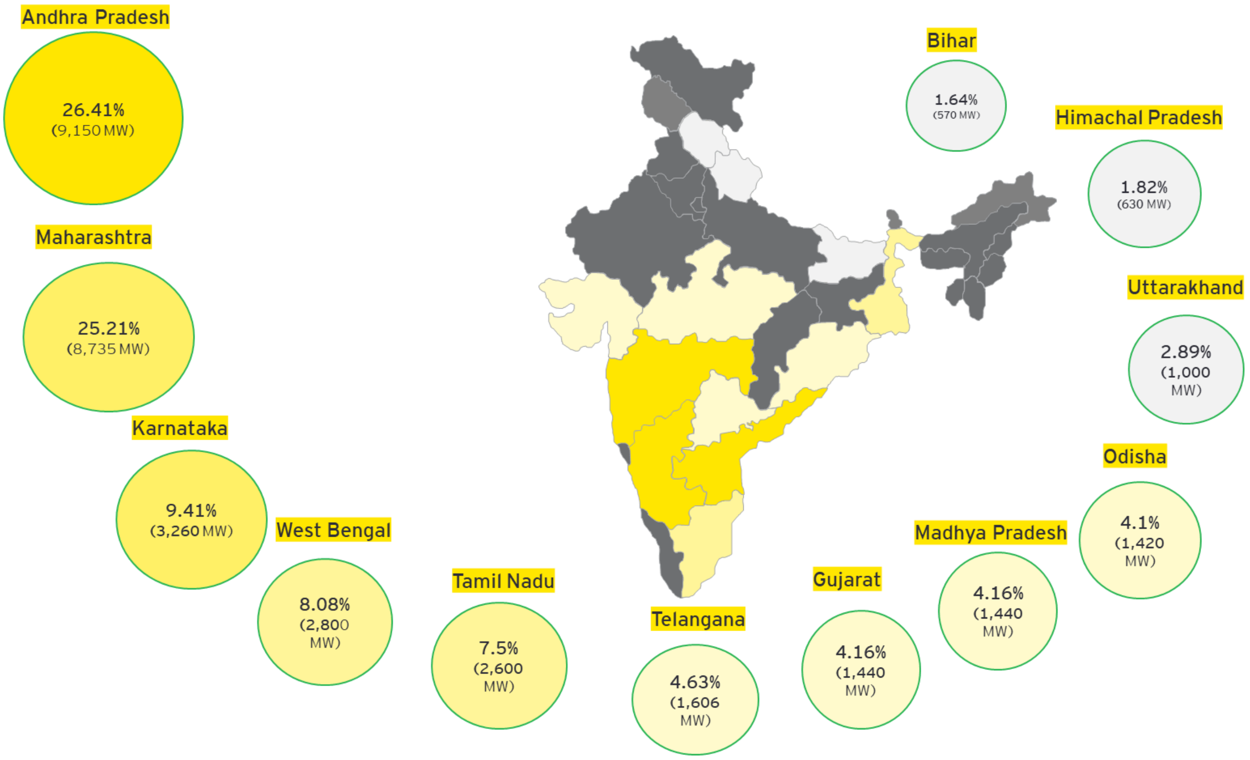


Figure 9: State level activity[7]

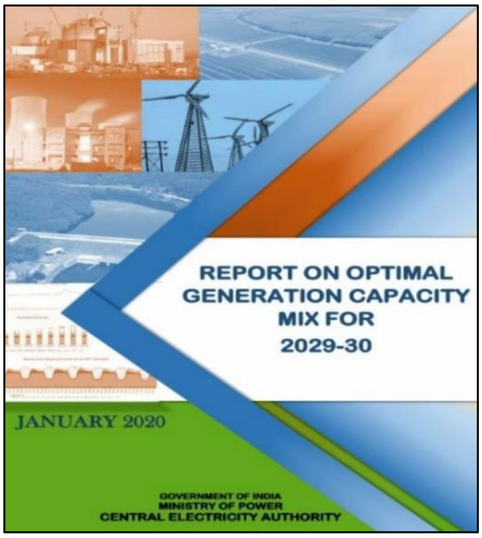
This chart shows all the project capacity which are under any stage of execution. The stages are **schemes constructed, schemes not constructed, DPR concurred by CEA, schemes under survey & investigation and schemes under PFR/ PIR/ DPR.**

- ~52% of the activity in the project execution is happening in the two states – Andhra Pradesh and Maharashtra.
- Only 12 states are showing traction in terms of PHS execution.

7 – CEA report titled "Status of Pumped Storage development in India as on 30.04.22

1.8. Future outlook of PSH in India as per CEA

Critical analysis of "Report on Optimal Generation Capacity Mix for 2029-30" by CEA (Jan 2020)



Indian scenario projection

- CEA in its "Report on Optimal Generation Capacity Mix for 2029-30" has predicted the outlook of PSH in India.
- It also identifies PSH (along with BESS) as commercially deployed solution for providing storage capacity.
- CEA estimate PHS installed capacity of 10 GW by 2029-30.
- CEA estimate battery energy storage system of 27GW with 4 hour storage requirement for 2022-30.

Table 1: Likely installed PHS capacity by 2029-30 (MW)

Scenario	Likely installed PHS capacity by 2029-30 (MW)	% Capacity mix (PHS/Total mix)
Base case (year 2021-22)	10,151	1.24%
Increase in Demand by 5% from base case demand	10,151	1.21%
Decrease in Demand by 5% from base case demand	10,151	1.28%
Increase in the battery cost projections by 2030 to $100/kWh	11,151	1.36%
Increase in the battery cost projections by 2030 to $125/kWh	11,151	1.37%

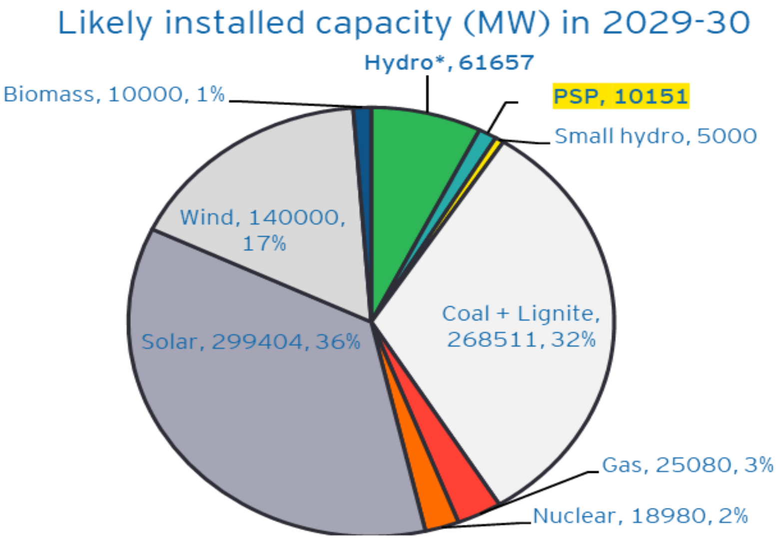


Figure 10: Likely installed capacity (MW) 2029-30

- Likely installed capacity mix of India (MW) in 2029-30 as per the CEA report.

**Here Hydro is including hydro imports of 5,856 MW and excluding PSP and small hydro.*

Chapter 2

Indian Energy Scenarios

2.1. Objectives

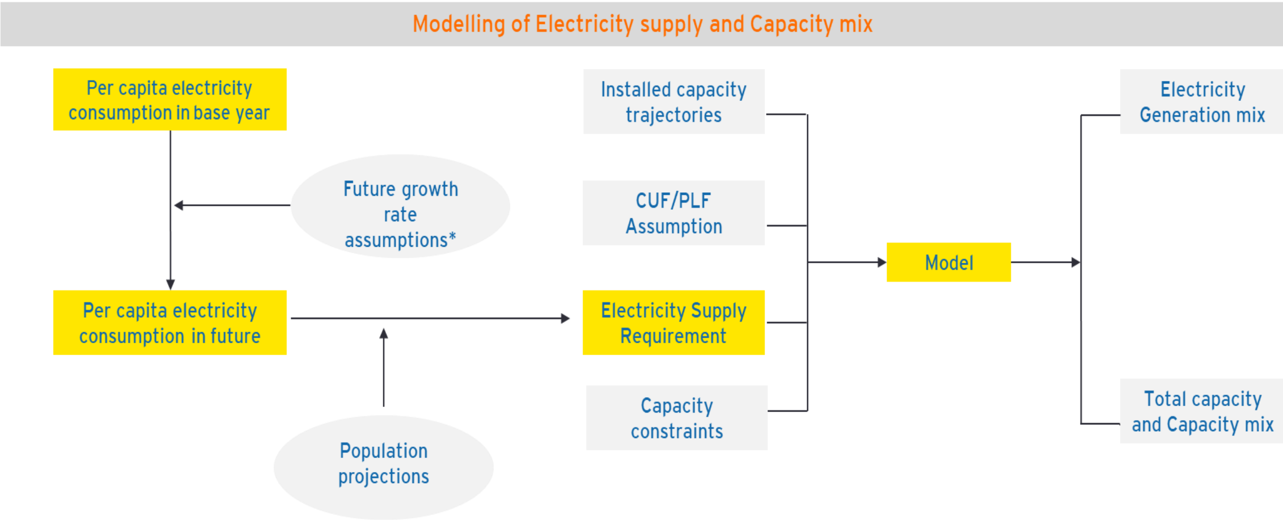
Objective	Context
▶ Indian Energy Scenarios up to 2030, 2040 & 2050. ▶ Projected requirement of Flexibility, Storage, Spinning Reserve and Ramping Capability in the Indian Grid in line with Electricity Demand. ▶ Projected share of Hydropower in the overall Indian Energy scenarios up to 2030, 2040 & 2050.	▶ Achievement of net-zero emissions target does not strictly mean complete decarbonization. A small number of emissions would still prevail, but they will be absorbed through CCS technology and increased carbon sink (i.e., afforestation). ▶ Power sector is relatively simpler to decarbonize, as compared to industry and transport. Hence, it can be assumed that it will get very close to zero emissions by 2060.

2.2. Assumptions

- Per capita electricity consumption (kWh) is assumed to grow at 5.1% CAGR, based on IESS2047 model and past trends. Population of India rises likely to 1639 million in 2050 (Ref. World Population Prospects 2019 report).
- Grid emission factors for coal and gas generation (0.98 and 0.43 kg CO2/kWh) are assumed to stay constant throughout the model's timeline. (Ref. CO2 baseline database for emission factors CEA March 2021). Electricity generation from gas is assumed to stay constant at 2020 levels, as the availability of gas is likely to be low in future as well.
- Nuclear (2060 capacity): Low (80 GW), High (200 GW), Medium (125 GW) (Ref. CEEW Net-zero scenarios).CCS (2060 capacity): Low (0 GW), High (80 GW), Medium (40 GW) (Ref. IEA Technology Roadmap for CCS).
- Large Hydro plants (2060 capacity): Low (80 GW), High (140 GW), Medium (100 GW) (Ref. Large hydro identified potential considered as the limiting capacity).
- The technology potentials considered for solar PV and onshore wind in the study(et.al. Deshmukh, R) are higher than the reported MNRE values. Geospatial and techno-economic analysis of wind and solar resources in India. Renewable Energy, 134, 947-960.).
- For other renewable technologies, technical potentials identified by MNRE are considered: Biomass: 28 GW, Small Hydro: 21 GW, Offshore Wind: 70 GW, Waste-to-electricity: 5.7 GW.
- PLF/CUF for technologies in 2019-20 have been estimated from the actual generation and installed capacity values in 2020. Future CUF values for PV and wind plants are assumed to increase. CEA Technology catalogue has also been referred for CUF values (Ref. CEA and DEA, Indian technology catalogue 2022, 2022).

2.3. Methodology - approach to project the future energy scenario of India

Flow Chart



Note: Per capita electricity consumption = Electricity generation/mid-year population.
Future growth rate decided based on past trend, literature survey and IESS2047 scenario results.

Technologies considered in the model: Coal, Gas, Coal-CCS, Nuclear, Hydro, PV, Wind, Biomass, small hydro, waste-to-electricity.

Power, industry, and transport are India's major CO2 emitter sectors. The power sector is relatively easier to decarbonize as compared to other sectors. Hence, it is expected that the power sector will get almost entirely decarbonized by 2060. The government of India also plans a gradual phase-down of coal power plants. Assuming a plant life of 30 years for a coal-based plant, it is expected that by 2060, a significant amount of the coal-based capacity will be retired from the mix. A small but finite amount of electricity generation is assumed to come from the gas power plants. Thus, the power sector will still contribute a small amount of CO_2 emissions in 2060.

Grid Emission Factor: The grid emission factor is defined as the CO_2 emissions per unit of electricity generation. As of 2020, the Indian grid has an average grid emission factor of 0.719 tCO_2/MWh.

Emission factor for coal-based plants: **0.98 tCO_2/MWh**

Emission factor for gas-based plants: **0.43 tCO_2/MWh**

The grid emission factor is a parameter considered to characterize the decarbonization of the grid or power sector. To achieve a net-zero emissions (or near-zero emissions) power sector, the grid emission factor must keep declining from 2020 until 2060. In 2060, the grid emission factor will be very low.

Per capita electricity consumption in India was 1031 kWh in 2020. It has grown at around 4.2% in the last decade. Future per capita electricity demand has been projected by assuming growth rates. These growth rate assumptions are based on past trends, IESS2047 model results, and a literature survey of published studies. The net-zero trajectory is expected to have a high share of demand electrification. Population projections are available in the World Population Prospects report[2]. Thus, future electricity generation requirement is calculated. This forms the first step of calculation in the models, as seen above (Flow chart).

The second step of the model is to estimate the future requirement of energy from different sources such as thermal, PV, wind, hydro, nuclear. Inputs at this stage of calculations are electricity generation requirement, capacity constraints, Capacity factor/Plant load factor assumptions. Apart from these inputs, three trajectories have been created for installed capacity of nuclear, large hydro and CCS technologies. These trajectories are also an input to the model at stage 2. The model balances annual electricity generation and demand to give electricity supply mix, installed capacity requirement and mix as outputs.

Details of Assumptions: -

1. Due to the improvement in the efficiency of thermal power plants, there is likely to be a small reduction in the emission factors for coal and gas power plants. For simplicity, emission factors for coal and gas technologies have been assumed to stay constant over the model's timeline.

2. Some coal plants are expected to be in the mix, but they will only be used for backup power generation. Thus, the role of coal-based power plants would be limited to providing grid support in case of emergencies. This scenario is likely to happen as the cost of coal as fuel is also expected to rise in coming years, making coal-based generation more expensive than RE-based generation.

3. Per capita electricity consumption has been calculated on the basis of gross generation by utilities and mid-year population. This definition is slightly different from CEA's definition, as per which,

$$Per\ capita\ consumption\ =\ gross\ available\ electricity/\ mid-year\ population$$

Gross available electricity considers electricity generated by utilities, non-utilities, and net imported electricity. To our study, we are focusing only on the electricity generated by utilities. Hence an adjusted definition is being used for per capita electricity consumption.

4. A net-zero by 2050 scenario created by TERI and Shell for India has projections for electricity mix for 2050[3]. There is a finite amount of gas-based electricity. Thus, the grid emission factor is very low but not zero. Values retrieved using a plot digitizer software suggest that the grid emission factor in 2050 for this scenario is ~0.015 tCO_2/MWh. Our study calculates the emission factor trajectory for the various scenarios generated through model. It can be used to visualize how the grid is being decarbonized over the period.

5. Past per capita electricity consumption trend shows that it has been growing at 4.24% in the last decade. However, to achieve a net-zero emissions target, high electrification of demand sectors is required, especially in the industry and transport sectors. Thus, the future growth rate will be more than what has been observed in the past.

CEEW's study on the net-zero scenario expects around 7500 TWh of electricity generation by 2050 and around 10000 TWh by 2060. As per net-zero scenario created by TERI and Shell mentioned above for India estimates electricity demand to be around 9000 TWh by 2050. The target year in this scenario is 20 years ahead of the declared goal. Hence this is an accelerated growth and decarbonization scenario.

A BAU-efficiency, High-electrification scenario generated from the IESS2047 model suggests that per capita electricity consumption would rise at a CAGR of 5.1% up to 2047. With this growth rate assumption, the total electricity supply in 2050 will be around 7500 TWh in 2050 and 12450 TWh in 2060. By 2060, certain sectors such as transport may achieve demand saturation. Hence the number may come down a little bit. However, the 2050 number is within the range, hence 5.1% CAGR is assumed for further calculations.

Brief details of the IESS2047 scenario:

i) **Residential:** Total number of households increase to 425 million in 2047 from 256 million in 2020 with 51% urbanization achieved by 2047.EPI of households has been growing at an average CAGR 0f 5% over the last decade. Due to the penetration of efficient appliances, this growth rate keeps declining gradually.

ii) **Commercial:** In commercial sector, share of air-conditioned floor space is assumed to increase for the buildings. However, penetration of ECBC-compliant buildings is assumed to rise to 25% by 2047.

iii) **Industry:** Aggressive electrification has been assumed in the industry sector, especially in the industries where coal is used for captive power generation. Share of electricity in fuel mix varies from industry to industry. Overall, grid electricity consumed by industries rises four times from 2020 to 2047.

iv) **Transport:** In transport sector, aggressive fuel substitution is assumed, especially in cars. By 2047, fuel mix of cars is assumed to be 40% electric, 7% Fuel cell-based and 10% CNG based and rest to be petrol/diesel. Similarly, aggressive fuel substitution is assumed in 2-wheelers, 3-wheelers, buses. Moreover, share of public transport in the total passenger transport is also assumed to increase to 65% in 2047, from 55% in 2020. Rail transport has been assumed to get entirely electrified. Share of rail in freight transport is also assumed to increase.

v) **Agriculture:** Diesel pumps are entirely replaced by electric pumps. By 2047, 80% pumps run on grid electricity and rest 20% are entirely solar-PV based pumps. Efficiency of electric pump fleet is assumed to increase to 45%.

vi) **Cooking:** It is assumed that biomass used for cooking will be replaced by cleaner fuels. Share of electric cooking will be 20% and 15% in urban and rural areas respectively, by 2047.

With sectoral assumptions such as aforementioned, scenario has been developed. It gives an overall CAGR of 5.1% for per capita electricity generation.

6. PLF/CUF for technologies in 2019-20 have been estimated from the actual generation and installed capacity values in 2020. Future CUF values for PV and wind plants are assumed to increase gradually. Future generation through gas power plants has been assumed to stay constant. For other dispatchable plants, a constant PLF has been assumed. These PLFs can also be considered as one of the inputs to the model.

2.4. Results - Energy supply mix 2030, 2040, 2050 & 2060 (high RE scenario vs high hydro)

Tabular Representation

Table 2: Energy supply mix (High RE) %

High RE Scenario (%)					
Source	2020	2030	2040	2050	2060
Gas Power Stations	3.50%	1.90%	1.09%	0.64%	0.39%
Coal power stations	71.87%	53.64%	32.99%	12.38%	0.00%
Carbon Capture Storage (CCS)	0.00%	0.00%	0.00%	0.00%	0.00%
Nuclear	3.36%	4.89%	4.54%	4.33%	4.22%
Hydro Power Generation	11.27%	8.16%	5.26%	3.40%	2.25%
Solar PV	3.62%	18.98%	35.08%	50.01%	58.80%
Onshore Wind	4.67%	10.22%	18.89%	26.93%	31.66%
Offshore Wind	0.00%	0.70%	0.95%	1.31%	1.81%
Small Hydro	0.68%	0.59%	0.49%	0.42%	0.37%
Biomass Based Electricity	1.00%	0.88%	0.65%	0.50%	0.39%
Waste to Electricity	0.03%	0.04%	0.05%	0.07%	0.10%

Table 3: Energy supply mix (High hydro) %

High Hydro Scenario (%)					
Source	2020	2030	2040	2050	2060
Gas Power Stations	3.50%	1.90%	1.09%	0.64%	0.39%
Coal power stations	71.87%	53.6%	33.4%	13.1%	0.0%
Carbon Capture Storage (CCS)	0.00%	0.0%	0.0%	0.0%	0.0%
Nuclear	3.36%	4.9%	4.5%	4.3%	4.2%
Hydro Power Generation	11.27%	8.2%	6.3%	4.9%	3.9%
Solar PV	3.62%	19.0%	34.1%	48.6%	57.7%
Onshore Wind	4.67%	10.2%	18.4%	26.1%	31.1%
Offshore Wind	0.00%	0.7%	0.9%	1.3%	1.8%
Small Hydro	0.68%	0.6%	0.5%	0.4%	0.4%
Biomass Based Electricity	1.00%	0.9%	0.7%	0.5%	0.4%
Waste to Electricity	0.03%	0.0%	0.1%	0.1%	0.1%

Graphical Representation

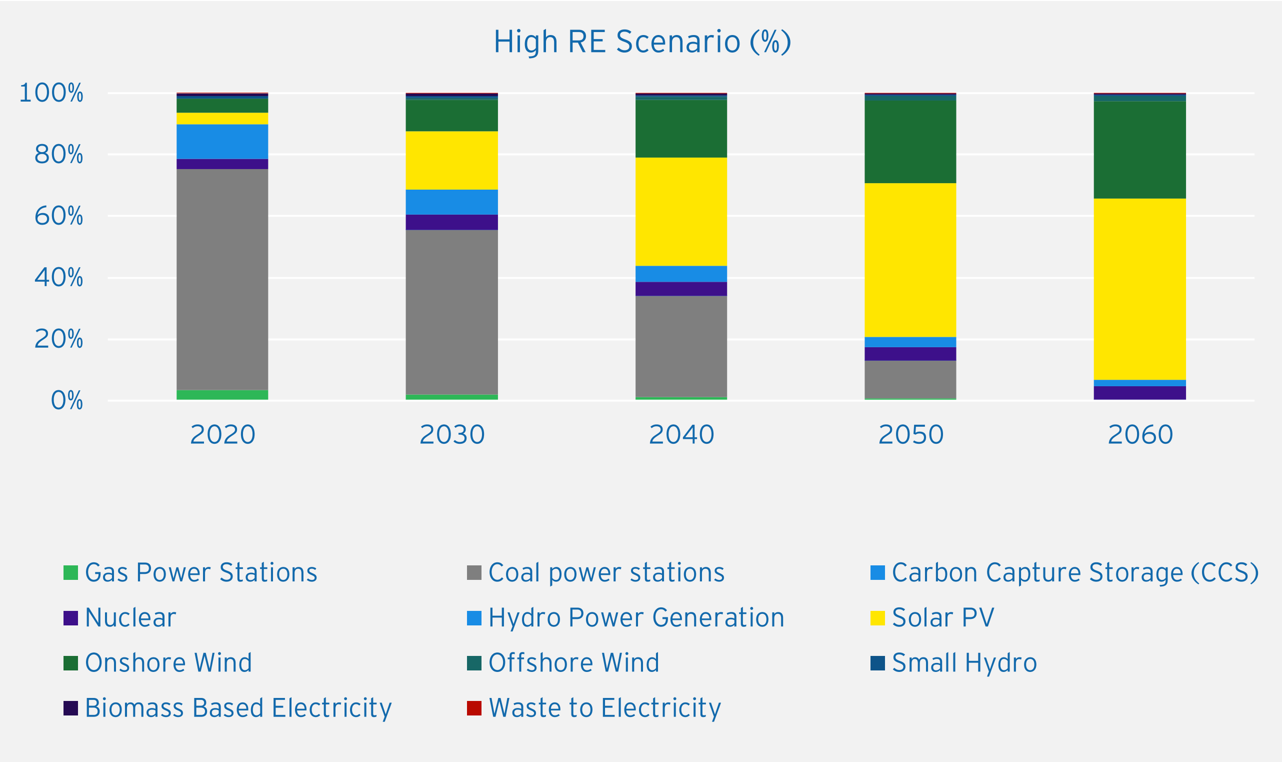


Figure 11: Supply mix (high RE) %

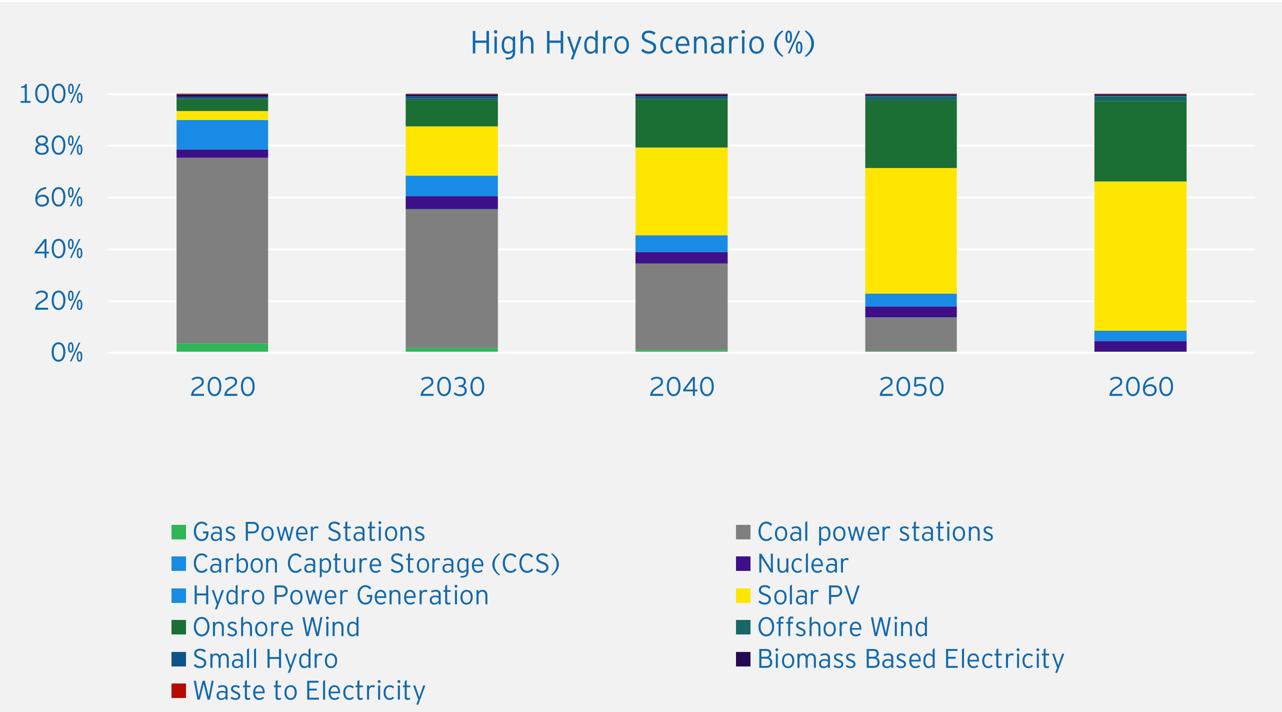


Figure 12: Supply Mix (High hydro) %

In both the scenarios, Solar PV will contribute more than 50% of the energy portfolio followed by onshore Wind, contribution from both Gas and Coal will almost be negligible as we come close to 2050 & 2060. It may be noted that hydro power capacity cannot go beyond the maximum hydro power potential.

2.5. Results - Electricity Generation as per the mix (High RE Scenario vs High Hydro)

Tabular Representation

Table 4: Generation as per mix (High RE) TWh

High RE Scenario					
Source, Unit: TWh	**2020**	**2030**	**2040**	**2050**	**2060**
Gas Power Stations	48.40	48.40	48.40	48.40	48.40
Coal power stations	994.00	1368.26	1465.82	930.79	0.00
Carbon Capture Storage (CCS)	0.00	0.05	0.05	0.05	0.05
Nuclear	46.40	124.83	201.57	325.49	525.60
Hydro Power Generation	155.80	208.06	233.71	255.95	280.32
Solar PV	50.10	484.13	1558.74	3758.96	7321.86
Onshore Wind	64.65	260.69	839.32	2024.06	3942.54
Offshore Wind	0.00	17.96	42.12	98.72	226.01
Small Hydro	9.45	15.03	21.82	31.68	45.99
Biomass Based Electricity	13.80	22.40	29.09	37.78	49.06
Waste to Electricity	0.40	0.95	2.23	5.27	12.46
Total	**1383.00**	**2550.75**	**4442.87**	**7517.16**	**12452.29**

Table 5: Generation as per mix (high hydro) TWh

High Hydro Scenario					
Source, Unit: TWh	**2020**	**2030**	**2040**	**2050**	**2060**
Gas Power Stations	48.40	48.40	48.40	48.40	48.40
Coal power stations	994.00	1368.26	1484.91	981.99	0.00
Carbon Capture Storage	0.00	0.05	0.05	0.05	0.05
Nuclear	46.40	124.83	201.57	325.49	525.60
Hydro Power Generation	155.80	208.06	281.63	371.70	490.56
Solar PV	50.10	484.13	1515.17	3650.46	7185.20
Onshore Wind	64.65	260.69	815.86	1965.63	3868.96
Offshore Wind	0.00	17.96	42.12	98.72	226.01
Small Hydro	9.45	15.03	21.82	31.68	45.99
Biomass Based Electricity	13.80	22.40	29.09	37.78	49.06
Waste to Electricity	0.40	0.95	2.23	5.27	12.46
Total	**1383.00**	**2550.75**	**4442.87**	**7517.16**	**12452.29**

Graphical Representation

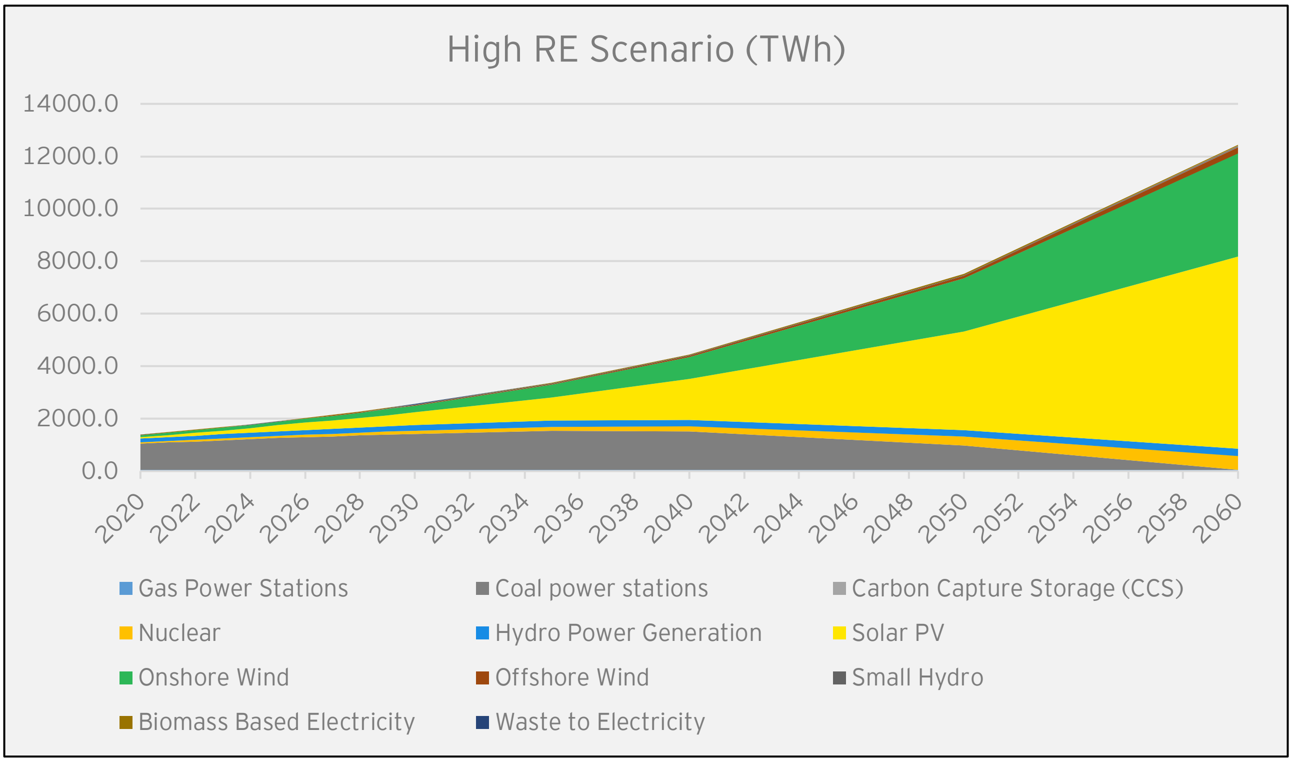


Figure 13: Generation Mix (High RE) TWh

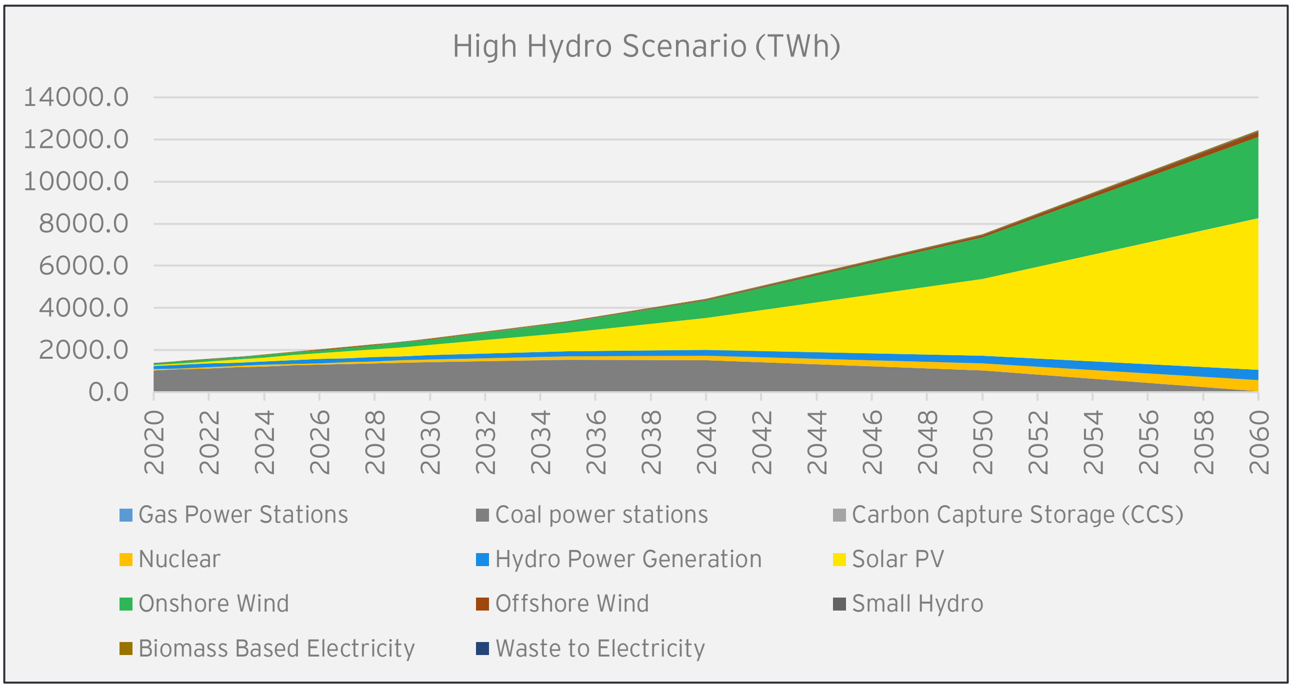


Figure 14: Generation Mix (high hydro) TWh

In both scenarios, generation from solar PV and onshore wind will be maximum, generation from Coal will almost be negligible as we come close to 2060, generation from Gas remains constant in both cases. Generation from hydro in 2050 in 1st and 2nd case are 280.3 TWh and 490.6TWh respectively.

2.6. Results – Installed Capacity as per the mix (High RE Scenario vs High Hydro)

Tabular Representation

Table 6: IC as per mix (High RE) GW

High RE Scenario					
Source, Unit: GW	**2020**	**2030**	**2040**	**2050**	**2060**
Gas	25.00	25.00	25.00	25.00	25.00
Coal	205.08	272.12	278.88	177.09	0.00
CCS	0.01	0.01	0.01	0.01	0.01
Nuclear	6.77	19.00	30.68	49.54	80.00
Hydro	45.71	60.90	66.70	73.05	80.00
PV	32.68	276.33	808.81	1787.94	3343.31
Onshore Wind	37.69	135.27	399.22	888.68	1607.36
Offshore wind	0.00	5.00	11.45	26.21	60.00
Small Hydro	4.73	6.86	9.96	14.46	21.00
Biomass	9.85	12.79	16.60	21.56	28.00
WTE	0.18	0.43	1.02	2.41	5.69
Total	**367.70**	**813.70**	**1648.34**	**3065.95**	**5250.38**

Table 7: IC as per mix (high hydro) GW

High Hydro Scenario					
Source, Unit: GW	**2020**	**2030**	**2040**	**2050**	**2060**
Gas	25.00	25.00	25.00	25.00	25.00
Coal	205.08	272.12	282.52	186.83	0.00
CCS	0.01	0.01	0.01	0.01	0.01
Nuclear	6.77	19.00	30.68	49.54	80.00
Hydro	45.71	60.90	80.37	106.08	140.00
PV	32.68	276.33	786.20	1736.33	3280.91
Onshore Wind	37.69	135.27	388.06	863.03	1577.36
Offshore wind	0.00	5.00	11.45	26.21	60.00
Small Hydro	4.73	6.86	9.96	14.46	21.00
Biomass	9.85	12.79	16.60	21.56	28.00
WTE	0.18	0.43	1.02	2.41	5.69
Total	**367.70**	**813.70**	**1631.89**	**3031.46**	**5217.98**

Graphical Representation

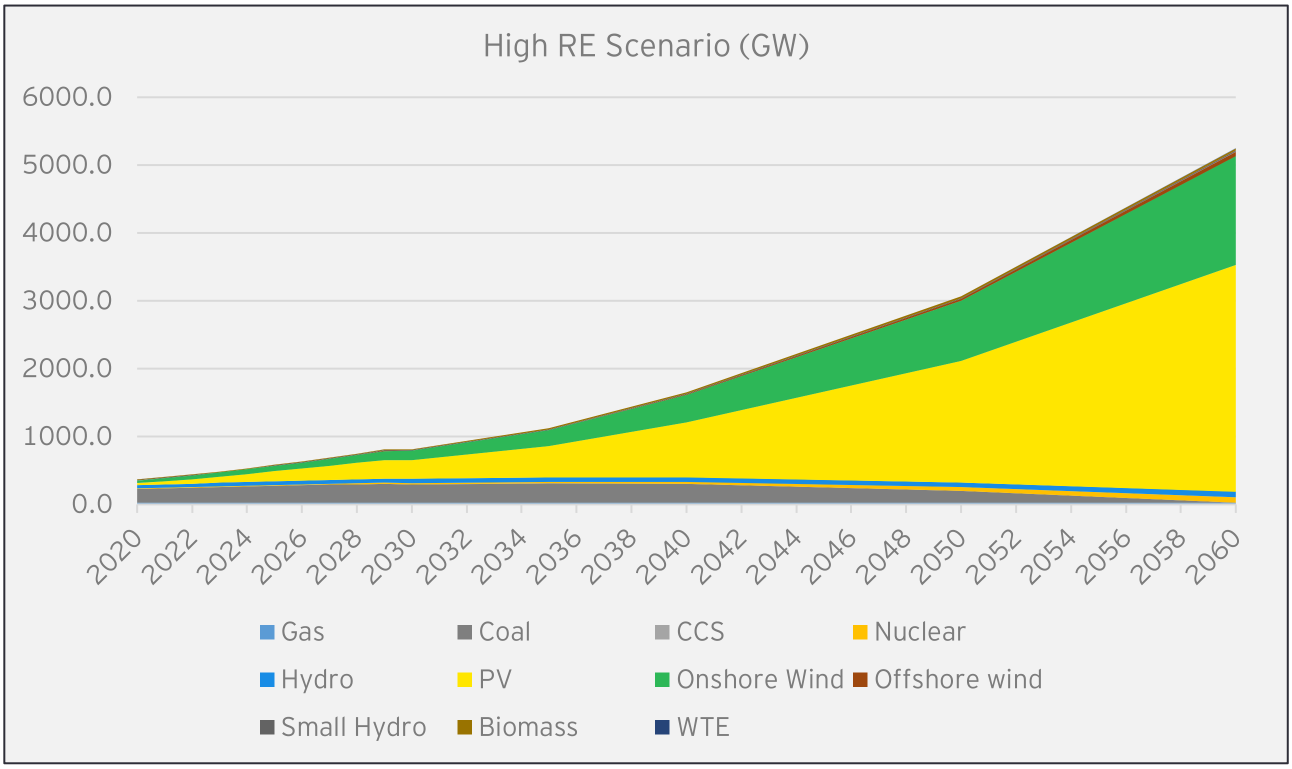


Figure 15: IC (high RE) GW

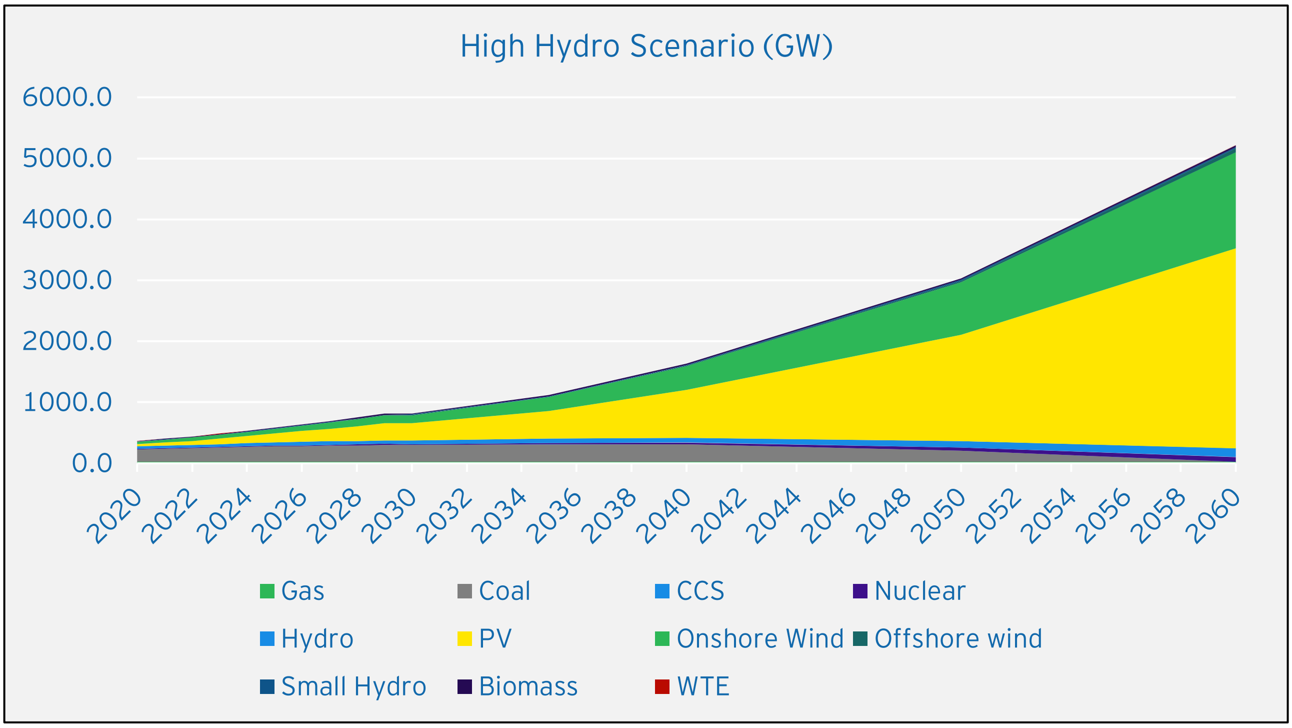


Figure 16: Installed Capacity (high hydro) GW

In both the scenarios, installed capacity of solar PV and onshore wind will be maximum, installed capacity of coal fired station will be almost negligible as we come close to 2060, capacity of gas fired stations will remain constant in both cases. Installed capacity of hydro power in 2050 in 1st and 2nd case will be 80 GW and 140 GW respectively.

2.7. Residual demand curve is reflection of flexibility estimation

To understand the ramping rate requirements in future, an analysis of hourly demand curves is required. We have hourly demand curves for one representative day of each month for 2015. We can assume it to be the same for the base year, i.e., 2020 as the consumption patterns have not changed within the 5 yrs.

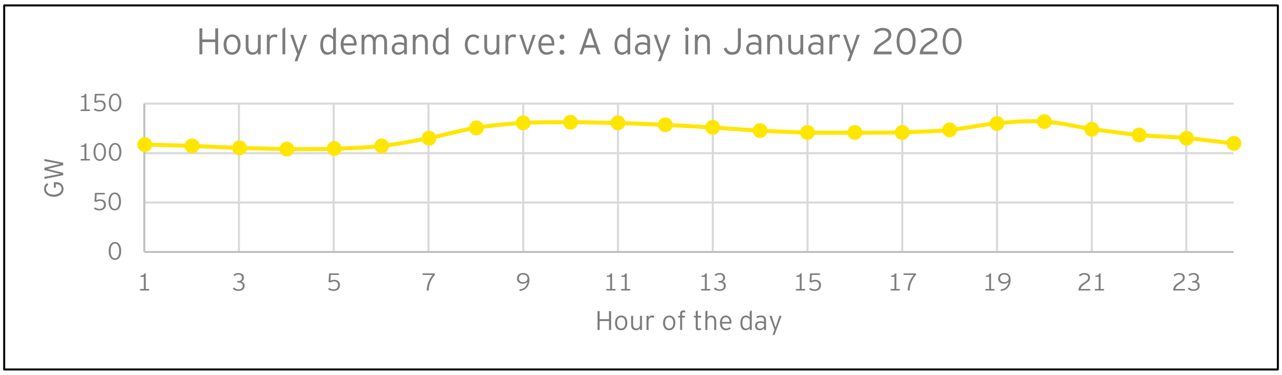


Figure 17: Hourly demand curve - A Day in January 2020

- As we create scenarios for 2030, 2040 and 2050, we also need to estimate the hourly demand curves for the respective years. High penetration of electric vehicles is expected in the future, which will contribute to the electricity demand in the future. It is important to examine the effect of EV charging on the shape of the demand curve.
- If the EV charging is not considered, we can simply scale the current demand curve to any future year by using a scaling factor based on the average electricity demand in the future year as compared to the base year. However, EV charging behaviour is likely to impact electricity consumption behaviour. Most of the electric demand for EVs is expected to come from electric cars and electric buses. These vehicles take more than 3 to 4 hours to get charged. And considering that they are used in the daytime for commute, they will most likely be charged at night, either in depots (buses) or household charging points (cars).
- The study published by AEEE presents a case study for EV charging in Delhi. The charging patterns show that EV charging takes place mainly between 12 midnight to 6 AM, and between 11 AM to 3 PM.
- For our study we have tried to replicate these patterns with modified charging timings: 11 PM to 6 am, and 12 noon to 4 PM. The charging pattern is shown in the image below.
- Due to this charging pattern, the resultant load shape is altered slightly. During the charging period, the load increases. However, the area under the curve, i.e., the total electricity consumed in the day would remain the same. To account for this fact, the excess load is assumed to be distributed evenly in the non-charging period, i.e., the remaining 13 hours of the day. With this modification, the shape of the load curve changes slightly, and the load curve becomes less peaky in nature.

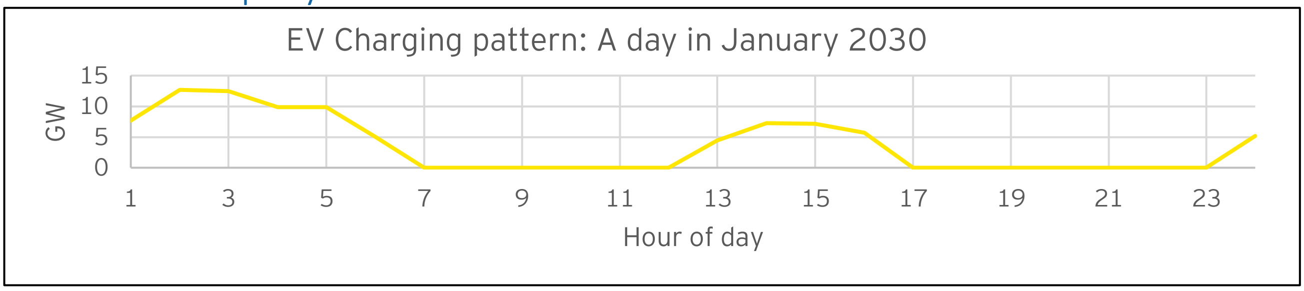


Figure 18: EV Charging pattern in a day

Through the demand analysis in the IESS2047 scenario, it is observed that the electricity demand for electric vehicles is:

Table 8: EV demand analysis

Particulars	2030	2040	2050
Electricity demand for EV (TWh)	76	200	361
Total electricity generation (TWh)	2551	4443	7517
After accounting for T&D losses			
EV charging demand in the total electricity generation	3.5%	5%	5.5%

Considering projections as per the previous slide, an illustrative scenario has been created to compare the demand curve shape with and without the impact of EV charging.

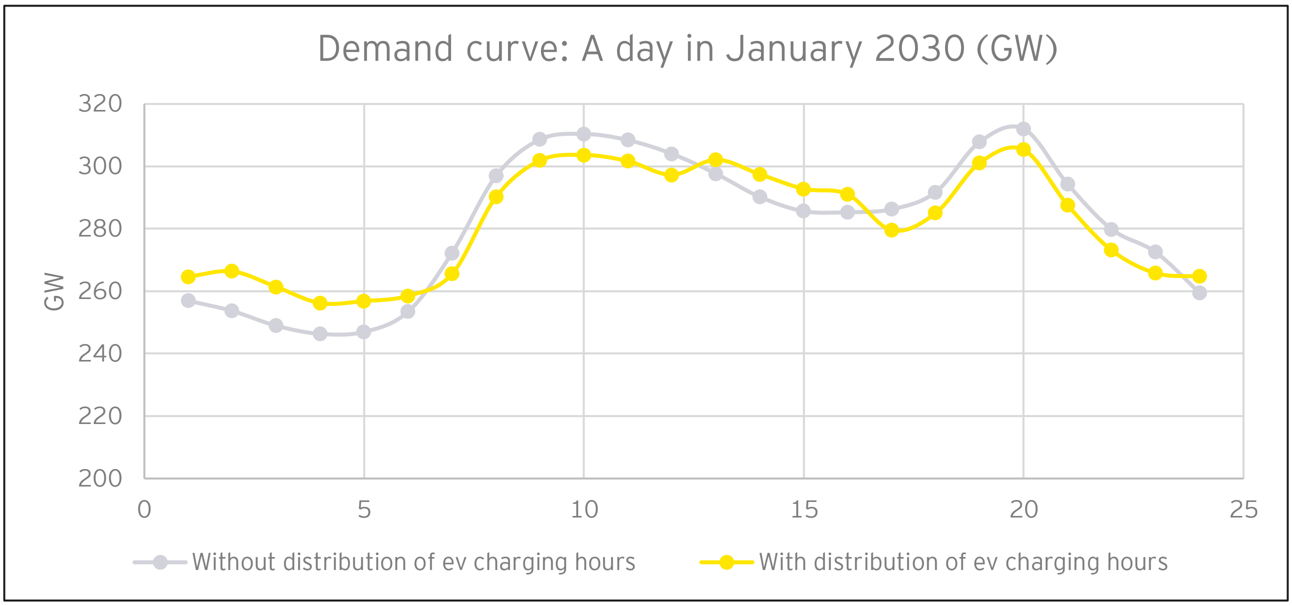


Figure 19: Demand curve: A Day in Jan 2030 (GW)

- For our study we have assumed charging timings: 11 PM to 6 am, and 12 noon to 4 PM.
- EV penetration won't be significantly impacting the load curve.

Note: Due to this charging pattern, the resultant load shape is altered slightly. During the charging period, the load increases. However, the area under the curve, i.e., remain the same.

Considering projections as per the previous slide, an illustrative scenario has been created to compare the demand curve shape with and without the impact of EV charging.

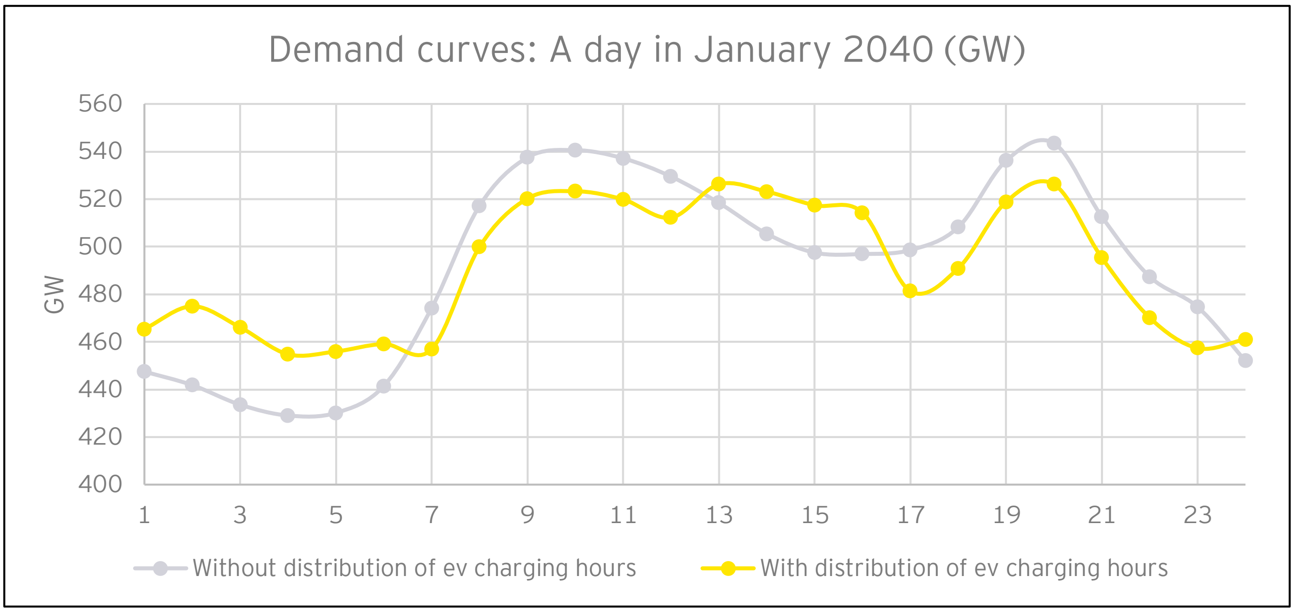


Figure 20: Demand curve: A Day in Jan 2040 (GW)

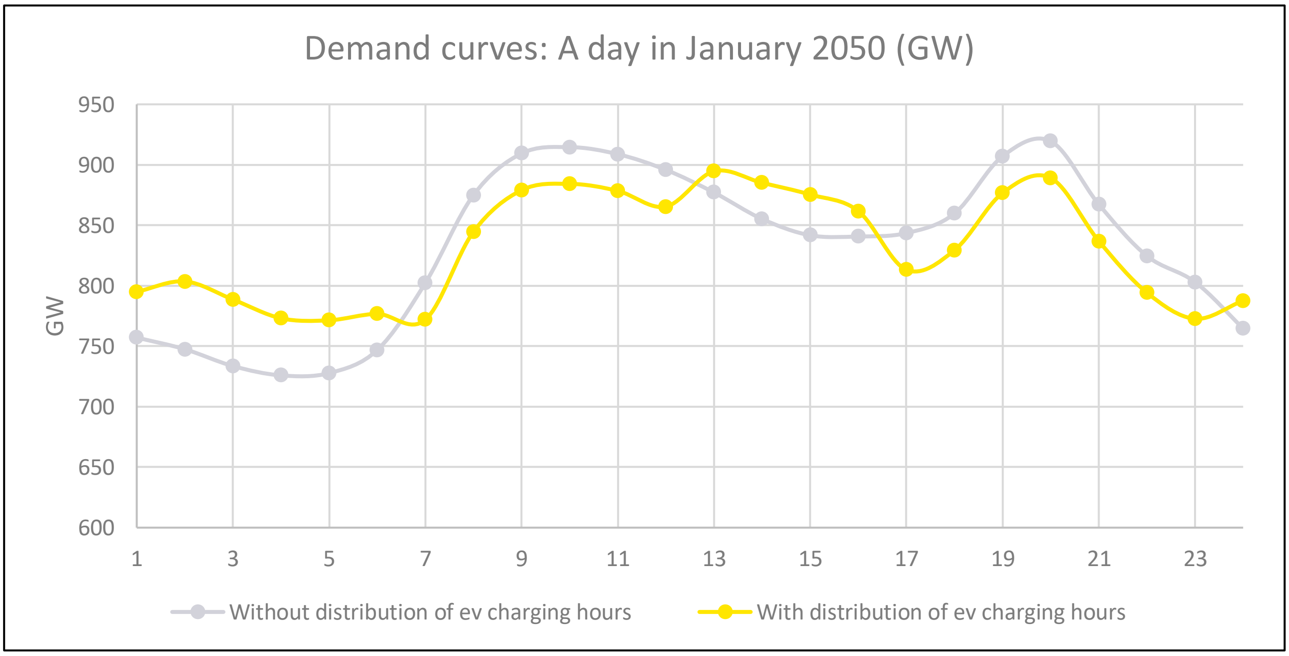
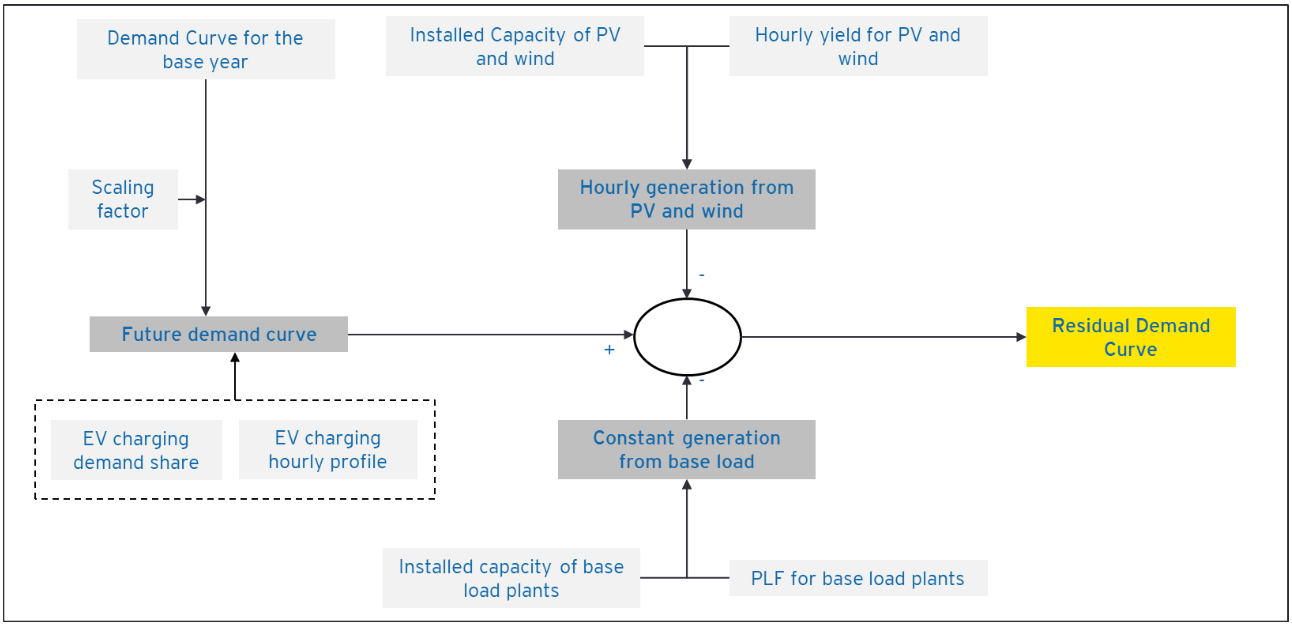


Figure 21: Demand curve: A Day in Jan 2050 (GW)

- If the EV charging is not considered, we can simply scale the current demand curve to any future year by using a scaling factor based on the average electricity demand in the future year as compared to the base year. However, EV charging behaviour is likely to impact electricity consumption behaviour.
- For our study we have assumed charging timings: 11 PM to 6 am, and 12 noon to 4 PM. During the charging period, the load increases. However, the area under the curve, i.e., the total electricity consumed in the day would remain the same. To account for this fact, the excess load is assumed to be distributed evenly in the non-charging period.

2.8. Flexibility Requirements Estimation – Flow chart



Flexibility requirement estimations are partly done outside the model. Based on the average annual demand of electricity, future hourly electricity demand curves are approximated. The calculations are based on PV, wind, nuclear and other RE capacities, and PV and wind yield curves, non-dispatchable electricity generation. Finally, residual demand curve is estimated to identify flexibility requirements. A flowchart of these steps has been shown in Flow Chart. Calculations for battery storage requirements are based on empirical relations and are entirely exogenous to the model.

2.9. Residual demand curve: High RE Scenario – A Day in 2030 (GW)

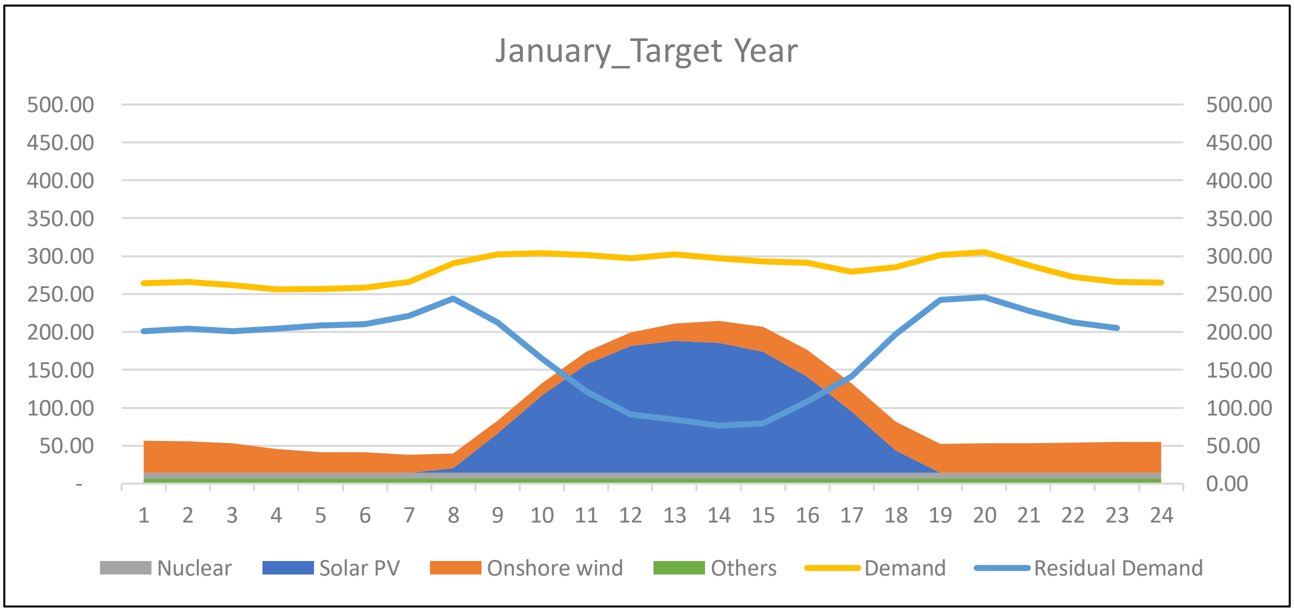


Figure 22: Residual demand curve: High RE Scenario – A Day in 2030 (GW)

Residual demand is Demand – (Solar + Wind + Nuclear Generation + others), In the above graph maximum residual demand value is 251.95 GW, minimum is 68.76 GW and average is 179 GW.

2.10. Residual demand curve: High RE Scenario – A Day in 2040 (GW)

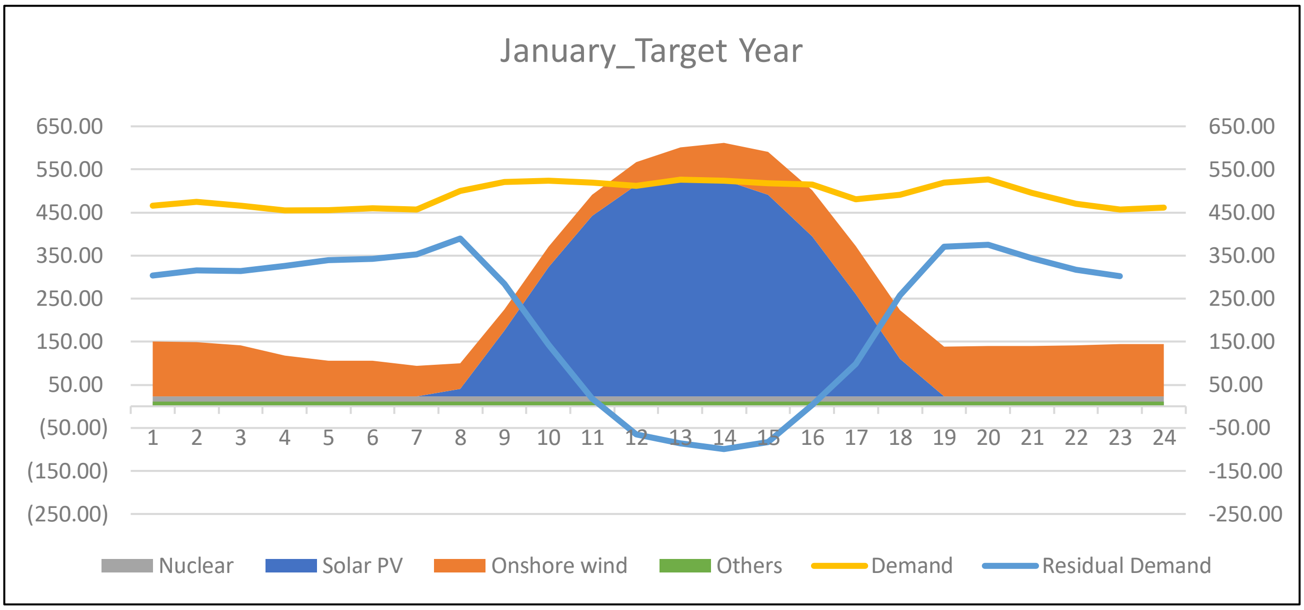


Figure 23: Residual demand curve: High RE Scenario – A Day in 2040

In the above graph maximum residual demand value is 413.91 GW, minimum is -100.23 GW and average is 225.57 GW.

2.11. Residual demand curve: High RE Scenario – A Day in 2050 (GW)

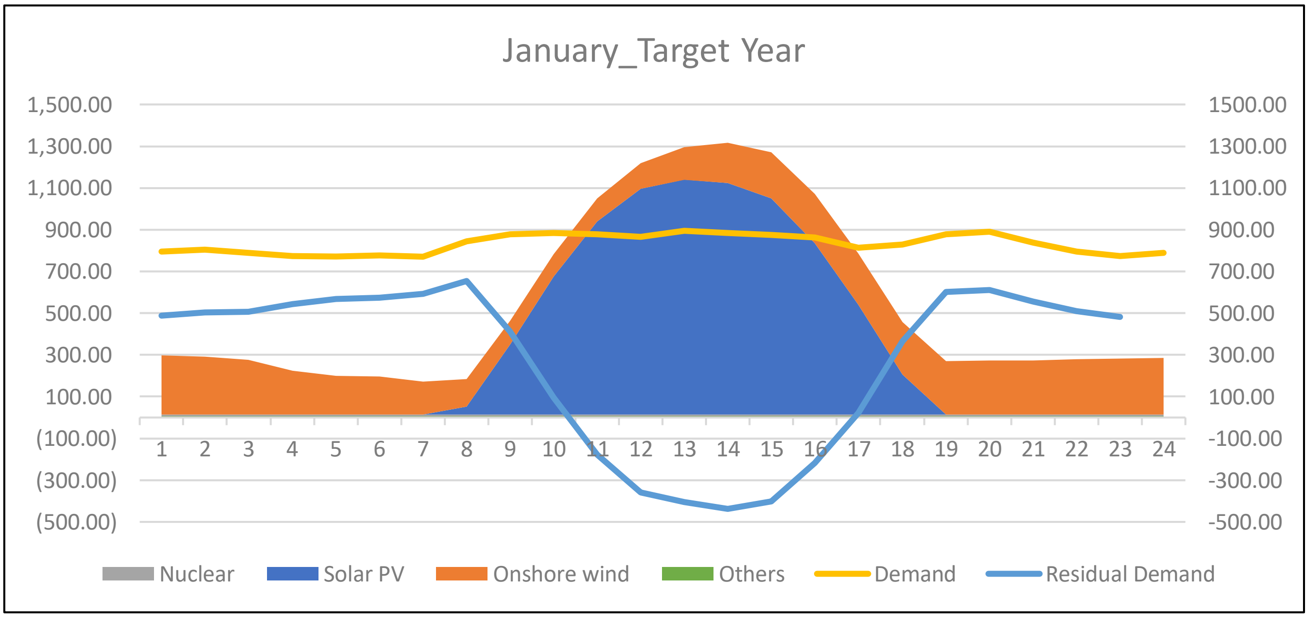


Figure 24: Residual demand curve: High RE Scenario – A Day in 2050

In the above graph maximum residual demand value is 648.32 GW, minimum is -503.88 GW and average is 237.96 GW.

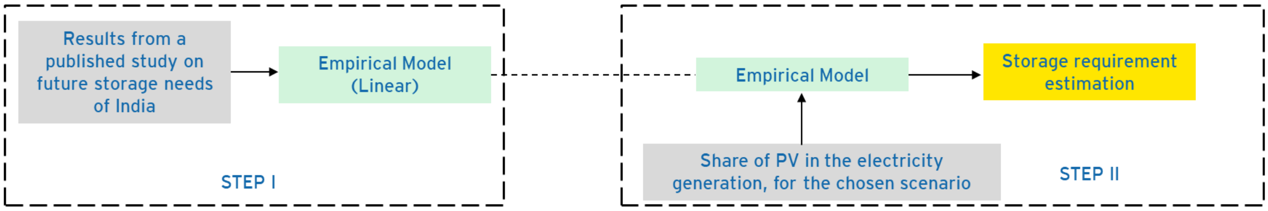
Generation from wind and solar power stations will be more than the required demand as we approach 2040. During such period and beyond, we need to have the energy storage system to provide the required flexibility to the grid in case of high PV and wind penetration.

2.11.1. Approach for the storage estimation calculations

Observation - The initial idea was that the overgeneration due to high PV and wind capacities would be considered as the input to the storage systems and accordingly the storage requirements (in GWh and GW) would be calculated. However, as 2030 results show, it is not necessary that storage is needed only when there is an overgeneration in the system.

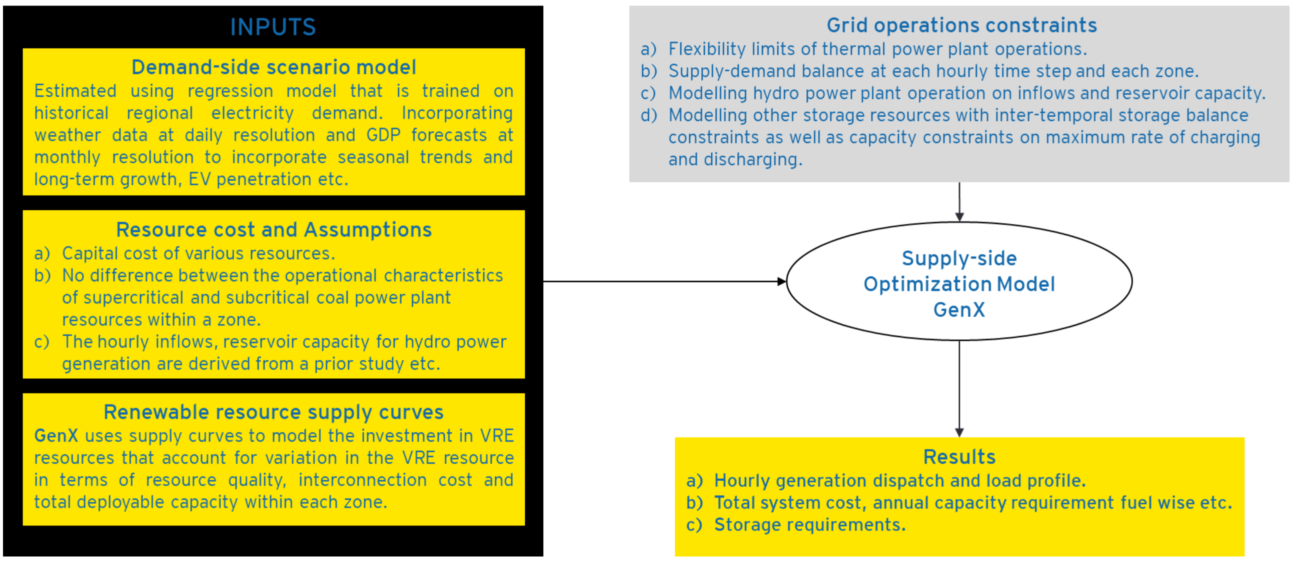
Approach – Many studies have been published about storage requirements for high renewable penetration cases for India. And there is likely to be an empirical relationship between the amount of storage required in the system to the share of installed capacity or electricity generation from PV/RE in the system. So, Linear regression coefficients have been calculated and those values are used to arrive at the storage estimation number.

Independent variable: Share of PV in electricity generation
Dependent variable: Amount of storage required per unit of electricity generation

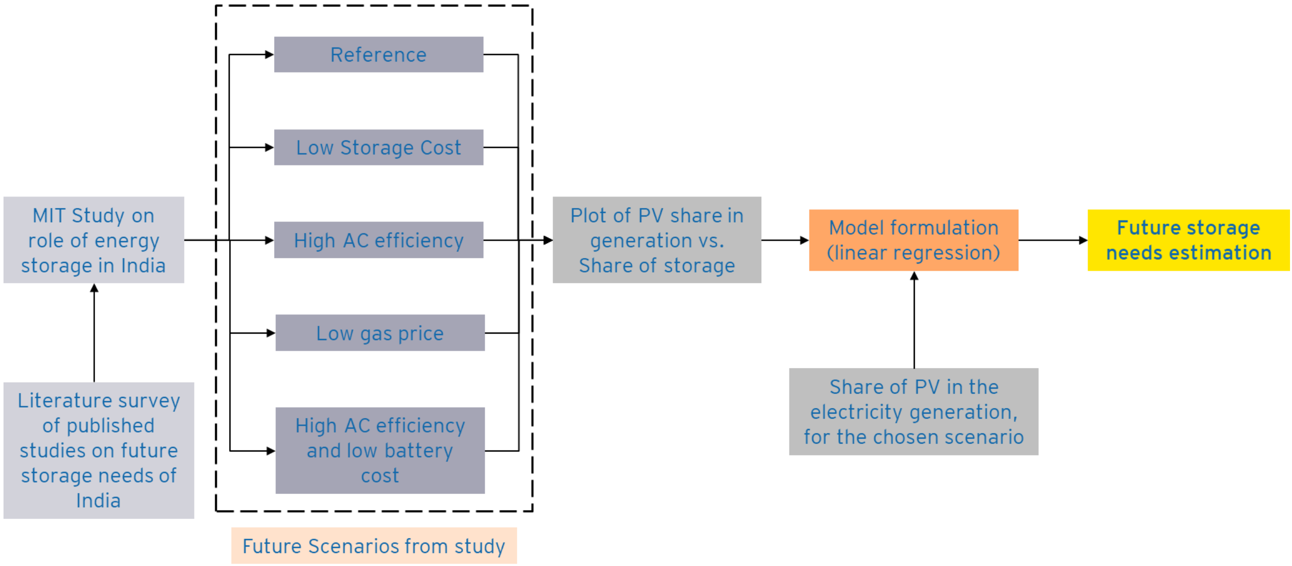


Note: This empirical relationship has been used for estimating the storage requirements in future. Numbers for 2040 and 2050 are within the range of numbers estimated by other studies. However, the numbers obtained for 2030 are lower than the numbers reported by other studies such as the optimal mix report by CEA. It is possible that the relationship may not hold strong for the lower values of the share of PV in the generation mix.

Methodology of the referred published study (Flow Chart)



Methodology for the storage estimation calculations (Flow Chart)
Empirical relation derived from a published study has been used to estimate storage needs



Source – Impact of demand growth on decarbonizing India's electricity sector and the role for energy storage by MIT

2.12. Results: Flexibility Requirement in high RE scenario

Table 9: Flexibility Requirement in high RE scenario (2030, 2040 & 2050)

Particular	2030	2040	2050
Maximum ramping rate requirement (GW/hour)	64.8	164.32	477.32
Storage capacity required (GWh)	50.7	1300	4097
2-Hrs battery storage (GW)	25.35	650	2048.50
6-Hrs PHP storage (GW)	8.45	216.67	682.84
As per Indian Grid Code, 5% of total rotating capacity is required as the spinning reserve			
spinning reserve (GW)	18.9	20.8	18
5% of peak load (GW)	16.7	29	49

- From the above results, there is significant growth in the storage capacity requirement from 50.7 GWh in 2030 to 4097 GWh in 2050.
- To meet the storage requirement of 50.7 GWh by 2030. Either 25.35 GW of BESS system needs to be developed or we can opt for 6 hrs of PSH of capacity 8.45 GW. Similarly, to crater the demand of storage which will reach 4097 GWh by 2050; 2048.50 GW and 682.84 GW for 2 hrs of BESS and 6 hrs of PSH will be required respectively, as per the study.
- Also, the similar pattern can be seen in Maximum ramping rate requirement (GW/hour) which has increased from 64.8 GW/h in 2030 to 477.32 GW/h in 2050.

2.13. Comparison of values for storage estimations

Table 10:Comparison of values for storage estimation

Studies	Scenario (GWh)	2030	2040	2050
WEC India (EY + IITB Analysis)	High RE	51	1300	4096
CEA Optimal Mix	Likely Scenario	108	-	-
	5% More Demand	100	-	-
	5% Less Demand	83	-	-
	More battery cost (100$/kWh)	92	-	-
	More battery cost (125$/kWh)	59	-	-
NITI-RMI Report: Need for Advanced Chemistry Cell Energy Storage	Accelerated scenario	128	-	-
	Conservative scenario	49	-	-
TERI: Renewable Energy Pathways: Modelling Integration of Wind and Solar in India by 2030	HRES (High RE scenario)	120	-	-
NREL: Storage Futures Study	Reference Case	380	1100	3200
Impact of demand growth on decarbonizing India's electricity sector and the role for energy storage by MIT	Reference Case	-	1072	1072
	Low Storage Cost	45	2639	4742
	High AC Efficiency	-	690	690
	Low Gas price Scenario	-	990	990
	High AC Efficiency & low storage cost	69	2143	3771

- Multiple scenarios aligned with net-zero future of India have been illustrated.
- Generation mix, capacity mix, flexibility requirements as well as share of hydropower in the mix have been estimated.

Few observations from the results:

- Solar PV and wind are mainstay of the future energy transition in all scenarios.
- A rapid deployment of storage (battery or PHP) is required to provide the required flexibility to the grid in case of high PV and wind penetration.
- Power sector emissions need to peak by 2040 and start declining afterwards to reach the decarbonization targets.
- Following conclusion may be drawn from figures 22, 23 and 24
    - Assuming that all RE generation will initially be fed into grid to reduce CO2 emission and only surplus RE will go towards battery charging, in such a scenario, BESS may not be viable solution and therefore policy impetus may be given to PSH.
    - However, if additional RE sources may be installed to fed power to BESS in such case BESS may be a viable solution. It may be notes that gestation of PSH is significantly high and therefore impact of any policy push can only be visible after 6-7 years, hence storage requirement in mid-term i.e., 2030 will largely met by BESS.
    - While choosing between BESS and PSH a comparative study in subsequent section.

RPO and Energy Storage Obligation (ESO):

The ESO shall be calculated in energy terms as a percentage of total consumption of electricity and shall be treated as fulfilled only when at least **85%** of the total energy stored in the Energy Storage System (ESS), on an annual basis, is procured from renewable resources.

Following percentage of total energy consumed shall be solar/wind along with/through storage: -

FY	Storage (on Energy basis)
2023-24	1.00%
2024-25	1.50%
2025-26	2.00%
2026-27	2.50%

FY	Storage (on Energy basis)
2027-28	3.00%
2028-29	3.50%
2029-30	4.00%

51 GWh of storage has been estimated in the year 2029-30 with our methodology. The energy supplied through storage contributes to 0.8-0.9% of the total electricity consumption. It is less than the stipulated 4% in the ESO obligation document.

Assuming 15% of T&D losses in the grid, the amount of storage required in the grid is 238 GWh in 2030 as per the ESO obligation, which is much greater than the projections made by multiple studies.

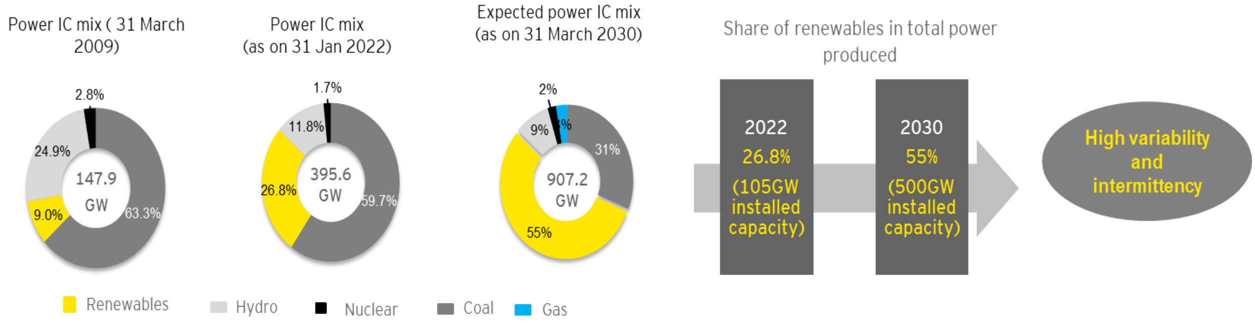
Note: As the energy storage obligation will be calculated in energy terms as a percentage of the total consumption of electricity. Therefore in order to estimate the total electricity consumption, we have assumed 10-15% T&D losses in the system i.e., from generation to consumption.

- Our estimation of 51 GWh of storage is based on the share of energy generated by solar PV in the grid. Thus, it is an estimate of the minimum requirement of storage in the grid.
- CEA's estimation is based on the minimum share of energy from storage from 2023-24 to 2029-30. Although the methodology behind those numbers is not available, the regulation has been set up in a way which will push the states/utilities toward including the storage components in their portfolio. It will prepare the grid for accommodating the intermittency.
- This will involve other components such as the use of storage as ancillary services, distribution-side installation, transmission investment deferral, etc.
- Our numbers being an estimate of the minimum requirement of storage and hence less than the storage requirements as specified in the regulation titled "Renewable purchase obligation and Energy storage obligation trajectory till 2029-30."
- Neither CEA's nor ours estimates is sufficient to fulfill the storage requirement as mentioned in above regulation (EPO).

2.14. Trends pushing for energy storage

Energy storage system (ESS) is expected to become enablers for large scale integration of Renewable Energy in India

The government has set an ambitious target to have **500 GW** of RE installed capacity by 2030. India is also making progress to increase the deployment of off-grid and residential solar across the country – the government aim to install **40 GW** rooftop solar by 2022.

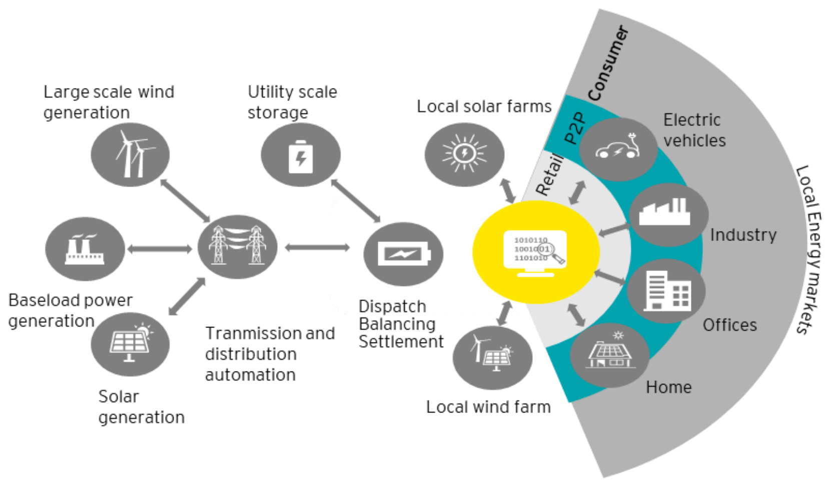


Energy Storage			
1	*Energy Shifting*	Battery storage can be located at the centralised wind and solar power production site to store excess renewable production for later periods. This process, in which excess renewable energy production is matched to periods of higher demand, is known as **energy supply shift.**	Time Scale: Minutes to hours
2	*Energy Smoothing*	A large cloud that blocks the sun may cause the output of a PV panel to fall as much as 90% almost instantly. A similar, though slower, loss of wind resources can cause an unexpected decrease in wind energy output. Smoothing renewable energy production helps maintain system reliability and voltage concerns. It does so by mitigating the very short-term fluctuating nature of variable renewable energy before feeding it into the grid.	Time Scale: Seconds to minutes

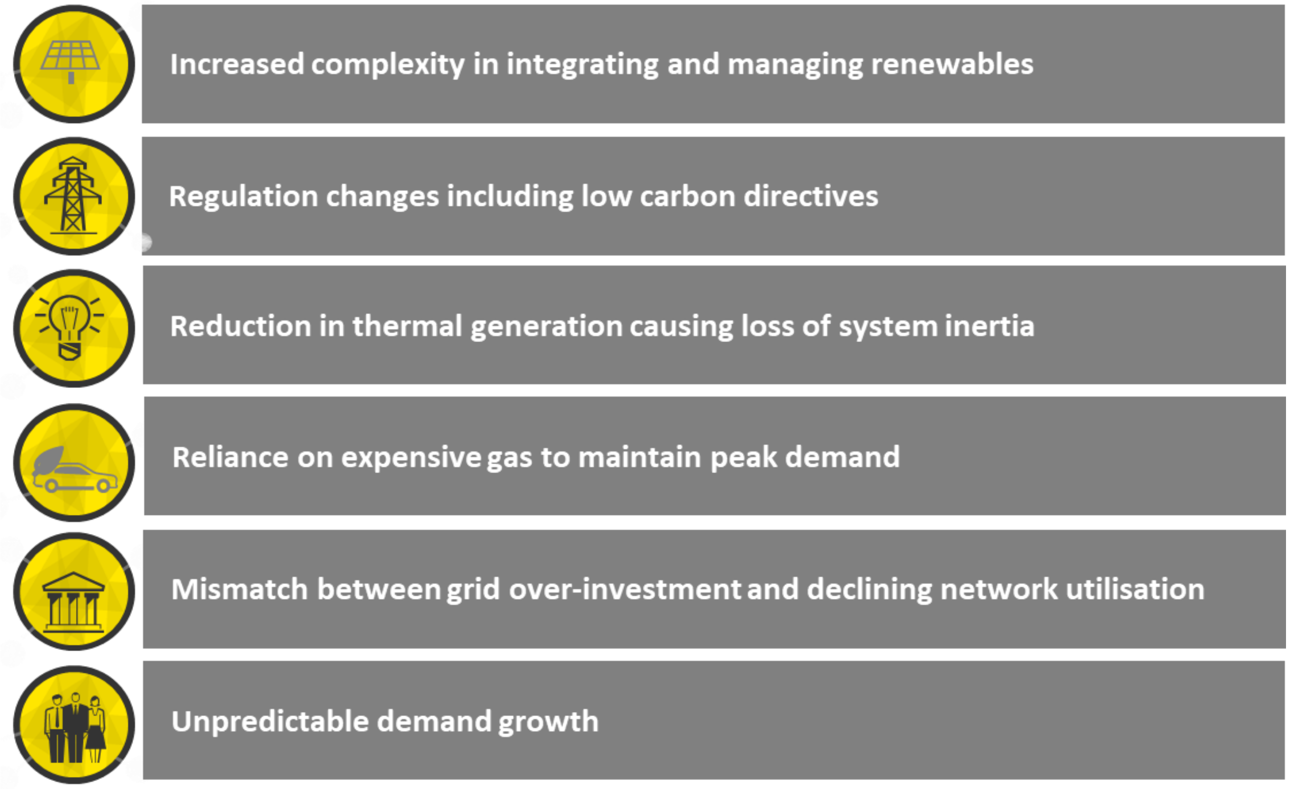
2.15. Need of flexibility is a demand factor for storage technology

Disruptions in energy sector driving the demand for technologies capable of providing options for flexible operations

Generation is becoming more distributed and closer to the end consumer and is becoming increasingly complex for networks to maintain the status quo without smarter solutions.



This sector disruption is creating an urgent need for flexibility



Upcoming T&D system will be a renewable heavy, frequency reactive and highly decentralised system, combined with peak less digitally controlled networks capable of bi-directional flows, with heavy use of batteries at sub-station and customer level.

2.16. Future needs of Energy Storage

IRENA study estimates that PSH may face a strong headwind from BESS technology.

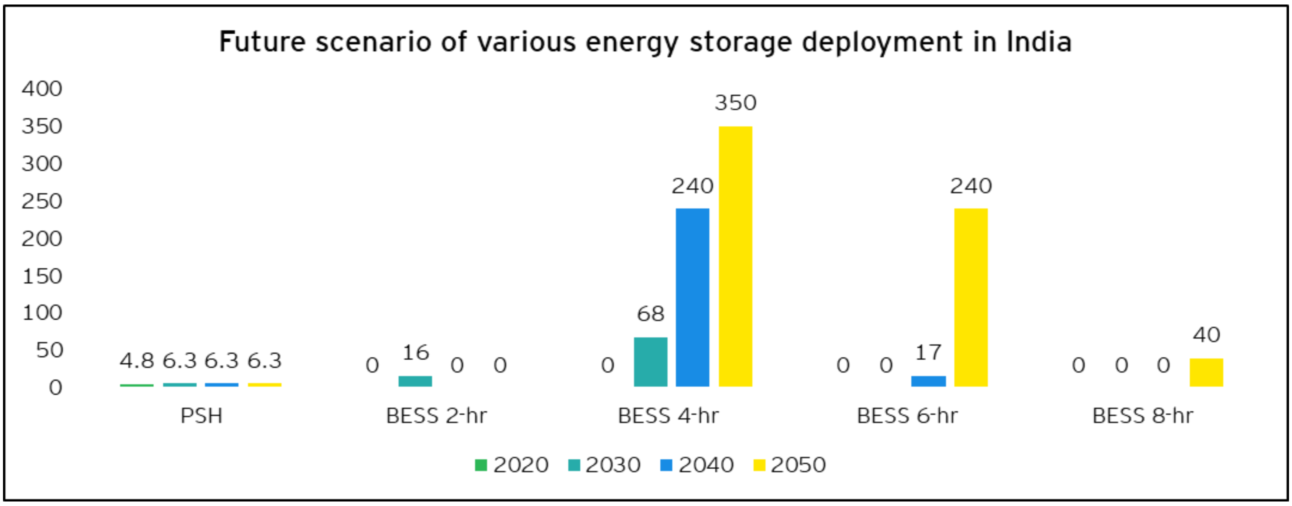


Figure 25: Future needs of Energy Storage[8]

- There is a stark difference in the capacity addition of Battery Energy Storage Solution (BESS), especially BESS- 4 hour, and PSH. The difference can be owed to the declining costs of BESS. Hence, it may create a limited investment opportunity for PSH going forward.
- Owing to tough fight with BESS falling cost, there is no new investment expected in PSH projects after 2030. It is stuck at the capacity of 6.3 GW.

IRENA study estimates that PSH may face a strong headwind from BESS technology which will not be the probable outlook for the PSP because of the following reasons: -

- As per the current policy push and interest from hydro power developers (both private and public), a lot many PSP will be commissioned in near future and therefore the analysis present in the above study may not be hold valid.
- India has a total PSH potential of 96.5 GW in 63 identified sites. In addition to it there are sites which has been explored by developers for development of PSP. CEA estimates PHS installed capacity of 10 GW by 2029-30.

8 – NREL report titled "Energy Storage in South Asia: Understanding the Role of Grid-Connected Energy Storage in South Asia's Power Sector Transformation" (July 2021)

Chapter 3

Techno-Commercial analysis of storage technology

3.1. Types of Storage Technologies

The categorization of technologies is based on their maturity and degree of commercialization

Energy storage could apply to different technologies ranging from pumped hydro storage, flywheels, super capacitors, compressed air, thermal energy storage and batteries. Advanced energy storage technologies are capable of dispatching electricity within seconds and can provide power back-up ranging from minutes to many hours.

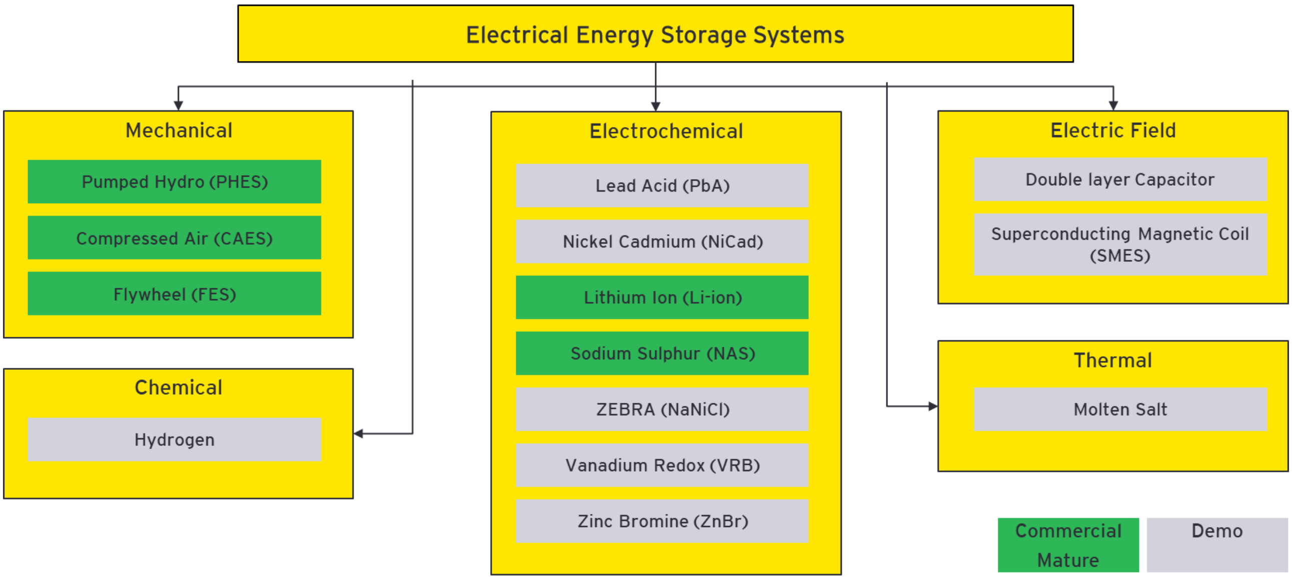


Figure 26: Types of Storage Technologies

3.2. Applications and Maturity of Storage Technology

Only few technologies are available at commercial scale

Table 11: Maturity and application of various technology

Storage	Maturity	Application
Pumped hydroelectric	Commercial	Load levelling, Peak shaving, Renewable integration, Time shifting, Frequency regulation, Black start, Reactive power capacity
Compressed air energy storage (underground)	Commercial	Load levelling, Renewable integration
Flywheels	Commercial	Frequency regulation
Superconductive magnetic energy storage	Demo	Power quality, Frequency regulation, Voltage Support
Electrochemical capacitors	Demo	Power quality, Frequency regulation, Voltage Support
Advanced lead acid batteries	Demo	Power quality, Frequency regulation, Voltage support, Renewable source integration
Lithium ion batteries	Commercial	Power quality, Frequency regulation
Sodium sulfur	Commercial	Time shifting, Frequency regulation, Renewable source integration
Vanadium flow redox	Demo	Peak shaving, Time shifting, Frequency regulation, Renewable source integration

3.3. Economic Evaluation of Alternate Energy Storage Options

Each type of available energy storage system (ESS) has specific attributes. These factors must be evaluated to choose the suitable technology for a specific purpose

Table 12: Economic evaluation of various storage technology

Technology	Energy density per unit of volume [Wh/L]	Power range [MW]	Sustained time of energy storage	Life time [Years]	Discharge time*	Number of cycles [cycles]	Cycle efficiency [%]
Pumped hydroelectric storage	0.5-2	30-5000	Hours-months	40-60	1-24h	10000-35000	~75-80
Flywheel energy storage	20-80	0.1-20	Second-minutes	15-20	1 sec- 15 min	~20000-100000	~89-95
Large compressed air energy storage	2-6	>=300	Hours-minutes	20-40	1-24 h+	8000-17000	~42-54 (~70% for A-CAES)
Li-ion (Lithium ion)	150-500	0-100	Min-d	5-15	Min-Hours+	1000-10000	~75-97
Na-S (Sodium-sulphur batteries)	150-250	0.5-35	Min.-Days.	10-15	Min.-Hour.+	4500-25000	~75-90

- Pumped hydroelectric and compressed air energy storage are used for bulk power management with largest power and energy capacities.
- Chemical batteries with 30 minutes to multiple hours of storage are commonly used for load shifting with project size in the range of 100kW to approximately 30MW.
- Flywheels, super capacitors, and superconducting magnetic energy storage can provide large amounts of power for very short amounts of time (seconds) and hence are valuable for providing frequency response to stabilize the grid.

Comparison of different electricity storage technologies for 1000/100 MW and 10h duration

Table 13: Comparison of different storage technology[9]

Above Average | Average | Below Average

Comparison Metrics		PSH	Li-ion	Lead Acid storage battery	Vanadium RF battery storage	CAES	Hydrogen fuel cells
Technical Capabilities	Technical readiness level	9	9	9	7	7	6
	Inertia for grid resilience	Mechanical	Synthetic	Synthetic	Synthetic	Mechanical	-
	Reactive power control	Yes	Yes	Yes	Yes	Yes	Yes
	Black start capability	Yes	Yes	Yes	Yes	Yes	Yes
Performance metrics	Round trip efficiency (%)	80%	86%	79%	68%	52%	35%
	Response time from standstill to full generation / (load) (s)	65 - 120 / 80-360	1-4	1-4	1-4	600/240	<1
	Number of storage cycles	13870	2000	739	5201	10403	10403
	Lifetime (years)	40	10	12	15	30	30
Costs 2020	Capex (USD/kW)	2202	3565	3558	3994	1089	3117
	Energy (USD/kW)	220	356	356	399	109	312
	Fixed O&M (USD/kW)	30	8.82	12.04	11.3	8.74	28.5
	Effective Capex of (USD/kW based on PSH life of 80 yrs & 6 % discount rate)	2910	10570	11720	16170	3110	8890
Estimated Costs 2030	Capex (USD/kW)	2202	2471	3050	3187	1089	1612
	Energy (USD/kW)	220	247	305	319	109	161
	Fixed O&M (USD/kW)	30	7.23	9.87	9.26	8.74	28.5
	Effective Capex of (USD/kW based on PSH life of 80 yrs & 6 % discount rate)	2910	8130	9050	9450	3110	4600

Note: Estimations based on the initial investment at end of lifetime including the replacement cost at every end-of-life period.

9 - US DOE, 2020 Grid Energy Storage Technology Cost and Performance Assessment

However, the estimated cost mentioned in the study is very high as compared to the projects which are developed in India for example -

- Total project completion cost including IDC and escalation for Bandu PSP, where both reservoir need to be built (as on March 2022) is INR 7.8 Cr/MW.
- While the total project completion cost for a PSP project in Odisha, where one reservoir is already present (as on March 2022) is INR 6.1 Cr/MW.

It is expected that PSP projects where one reservoir is already present the cost per MW will go down even further.

10 - PFR report

3.4. Levelized Generation Cost of Storage Technology

LCOE : Pumped hydroelectric storage – Case study: Bandu Pumped Storage Project

(Double reservoir)

Pre-Feasibility Report of Bandu Nala Pumped Storage Project (900 MW) was prepared by WBSEDCL in the year 2013 and further updated in year 2018 by WAPCOS. The proposed Bandu Pumped Storage Project is located near Ayodhya village in Purulia district of West Bengal, India.

Table 14: Project details

Particular	Details
Project	Bandu Pumped Storage Project
Development Basis	Design, Build, Finance, Operate and Transfer (DBFOT)
Location	Ajodhya Hill Area, Purulia District, West Bengal

The Scheme envisages construction of:

- 71-metre high Rockfill upper dam with central impervious clay core across river Bandu to provide a live storage of 13.49 million cum with Full Reservoir Level at 480.00 meter and Minimum draw down Level at 460.83 meter. Poundage for 1 MCM Irrigation requirement is also proposed in Upper Reservoir. The MDDL for Irrigation depletion is EL 458.75m.
- 53-metre high Rockfill lower dam with central impervious clay core across river Bandu to provide a live storage of 13.49 million cum with Full Reservoir Level at 340.44 meter and Minimum Draw down Level at 325.00 meter.
- An underground powerhouse with four numbers Francis type reversible pump-turbine of capacity 225/255 MW.

Table 15: LCOE_PSP - assumptions and results[10]

Assumptions

Particular	Value
Installed Capacity (MW)	900.00
No. of Units	4.00
Total Project completion Cost including IDC and escalation (INR crore)	6,992.18
Completion Time (months)	75.00
COD (year)	2029
Hours of daily Peaking Operation	5.00
Energy Generation (MU/Year)	1642.50
Pumping Energy (MU/Year)	2135.25
Cycle Efficiency	76.92%
O&M (% of total project cost)	3.5%
Debt : Equity	75:25

Assumptions

Particular	Value
Total cost at December 2017 Level (INR Cr) (Note: This amount includes the likely construction cost plus 25% thereof by way of financing costs, physical and price contingencies etc.)	4700.00
Hard cost at December 2017 Level (INR Cr) (25% reduction from RFP value as per note in RFP)	3760.00
Escalation factor till March 2022 Level	1.30
Escalation rate for EPC post 2022	4.63%

Results

Particular / (base case)	Value
E-IRR	10.79%
LCOE with ROE wrt COD including cost of energy (INR/kWh)	12.06
LCOE with ROE without cost of energy (INR/kWh)	7.93

LCOE : Pumped hydroelectric storage – Case study: Pumped Storage Project (Odisha state)

(Single reservoir)

The approximate project cost is about 2978 crore in April 2018 (PL), i.e., about 5 crore/MW. This project will improve the install capacity and peaking power in the state. With install capacity of 4 X 150 MW, daily generation of 5 hrs peaking would be 3000. MW-hr with annual generation of 729 MU.

Assumptions

Particular	Value
Installed Capacity (MW)	600.00
No. of Units	4.00
Total Project completion Cost including IDC and escalation (INR crore)	4,644.52
Completion Time (months)	60.00
COD (year)	2028
Hours of daily Peaking Operation	5.00
Energy Generation (MU/Year)	729
Pumping Energy (MU/Year)	972
Cycle Efficiency	75.00%
O&M (% of total project cost)	3.5%
Debt : Equity	75:25

Assumptions

Particular	Value
Total cost at December 2018 Level (INR Cr)	2704.34
Escalation factor till March 2022 Level	1.30
Escalation rate for EPC post 2022	4.63%

Results

Particular / (base case)	Value
E-IRR	12.29%
LCOE with ROE wrt COD including cost of energy (INR/kWh)	11.91
LCOE with ROE without cost of energy (INR/kWh)	7.76

Levelized Generation Cost of Storage Technology

LCOE : BESS - Case study: Lazard's Levelized Cost of Storage study

Table 16: LCOE_BESS - assumptions and results[11]

Assumptions

Particular	Value
Power rating (MW)	100
Duration (Hours)	2
Usable Energy (MWh)	200
90% depth od discharge cycles/day	1
Operating days/year	350
Debt : Equity	1:4

Assumptions

Particular	Value
Total Installed Cost ($/MWh)	172
O&M ($/MWh)	20
Charging Cost ($/kWh)	0.042
Charging cost escalator (%)	1.87%
Efficiency (%)	91%

Results

Particular	Value
IRR	12%
Levelized Storage Cost ($/MWh)	146
Levelized Storage Cost (INR/MWh)	11,431.80
Levelized Storage Cost (INR/kWh) excluding cost of storage	11.43

11: Microsoft PowerPoint - Lazard's Levelized Cost of Storage - Version 7.0 vDraft2.pptx, EY Market research

Comparison of BESS Tenders

Table 17: Comparison of BESS Tenders

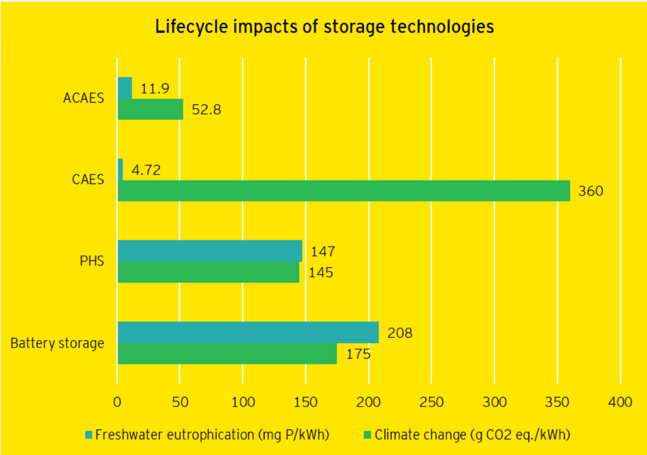
Tender Conditions	SECI Tender	KSEB Tender
BESS Capacity	500 MW/ 1000 MWh	10 MW/ 20 MWh
No. of Cycles	2 (1cycle of 2 hours each)	2 (1cycle of 2 hours each)
Project Location	In the vicinity of Fatehgarh-III Substations of the ISTS network, in the State of Rajasthan	In the vicinity of 220 kV Mylatti Substation
Grid Connectivity	@ 400/ 220 KV	220/110 kV at Mylatti Substation
Type of Business Arrangement	**BOOT** Post completion of contract period, the facility is to be transferred to SECI	BOOT Post completion of contract period, the facility is to be transferred to KSEB
Contract Period	12 years	12 years
Contracted Capacity	SECI's Obligation- 60% Free Capacity for Developer- 40%	100% Capacity to be off taken
Source of Energy	For charging purposes of 60% capacity, Buying entity shall source the Electricity	KSEB shall provide electricity for charging purposes
Successful bidder offering the capacity@	INR 10,83,500 per MW/ Month INR 9.03 per kW/h , GST and cost of energy additional	INR 11,25,001 per MW/ Month only storage cost INR 9.38 per kW/h , GST and cost of energy additional

- From above analysis we have observed that the LCOE of BESS is higher than that of PSP.
- Also in PSP, the LCOE of projects where only one reservoir needs to be built is less than the projects where two reservoir needs to be built.

  Therefore the pecking order of the completion cost and hence tariff will be PSP where one reservoir needs to be build followed by PSP where two reservoir needs to be build followed by BESS.

3.5. Comparative Life Cycle Analysis (LCA) of various Storage technologies

PHS has lesser environmental implications than battery storage solution.



- Hottenroth, Peters provide a comparative LCA of utility-scale storage solutions, namely PHS and battery, for the **German electricity grid**, assuming 2600 GWh of electricity provision per year over 80 years.
- Lifecycle impact in terms of environmental effect is measured through two parameters - **freshwater eutrophication** and **climate change**.
- **PHS is performing better in comparison with battery storage** on the abovementioned two parameters.

Note-

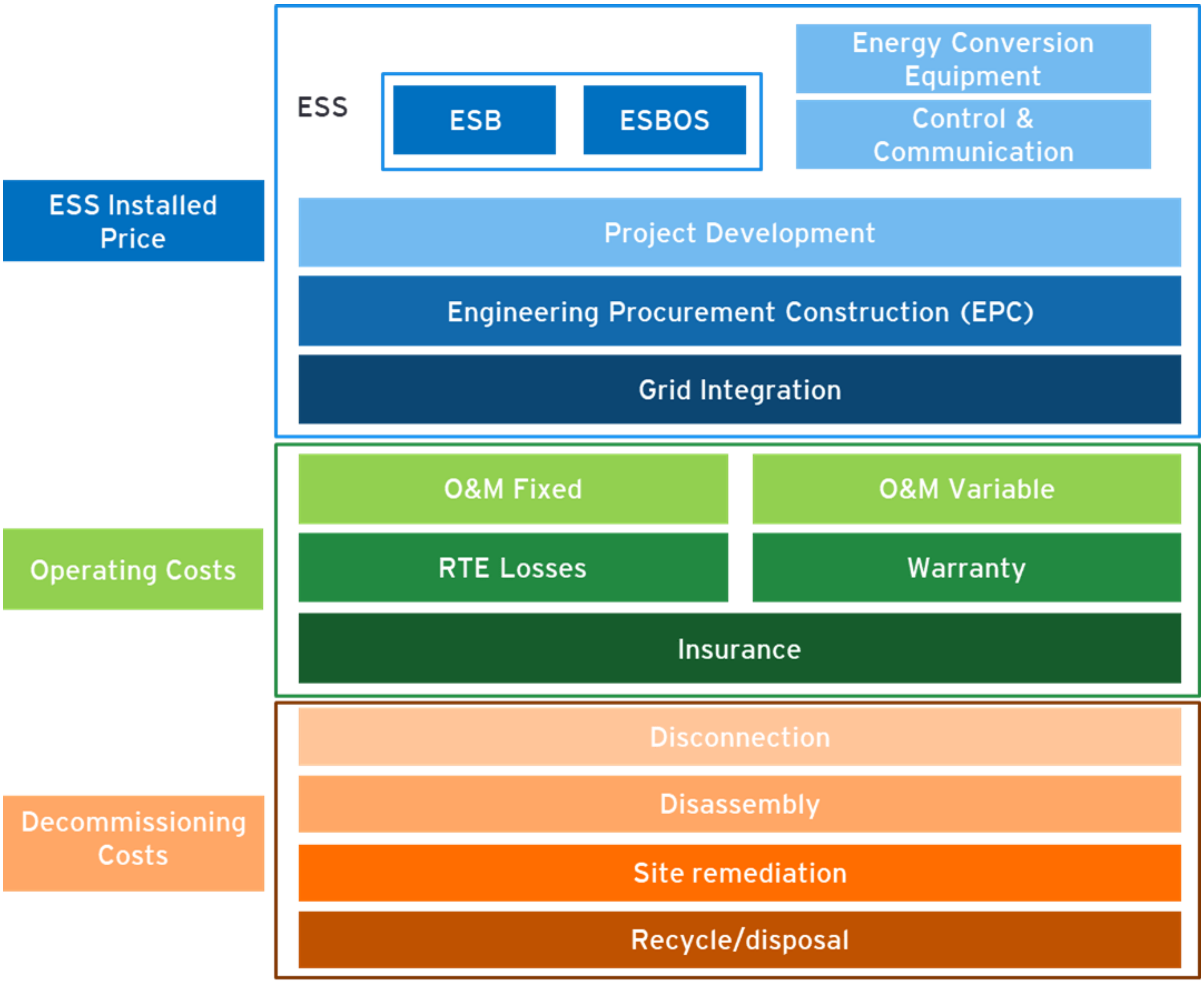
ACAES - Adiabatic Compressed Air Energy Storage; CAES - Compressed Air Energy Storage; PHS - Pumped Hydro Storage

Source - UNECE report titled "Life Cycle Assessment of Electricity Generation Options"

Figure 27: Life cycle impacts of storage technologies[12]

- Life cycle Assessment (LCA) is a systemic approach that allows evaluating the environmental performance through the life cycle of a product system.
- This approach states that the environmental impact has a wider scope than being just related to a single location or service, but rather it occurs along all the life cycle of products and services.
- LCA is a technique for estimating the environmental aspects and potential impacts related with a product.

12 – http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.468.9733&rep=rep1&type=pdf, https://repository.najah.edu/bitstream/handle/20.500.11888/13294/%D8%A7%D9%84%D8%B1%D8%B3%D8%A7%D9%84%D8%A9.pdf?sequence=1&isAllowed=y,



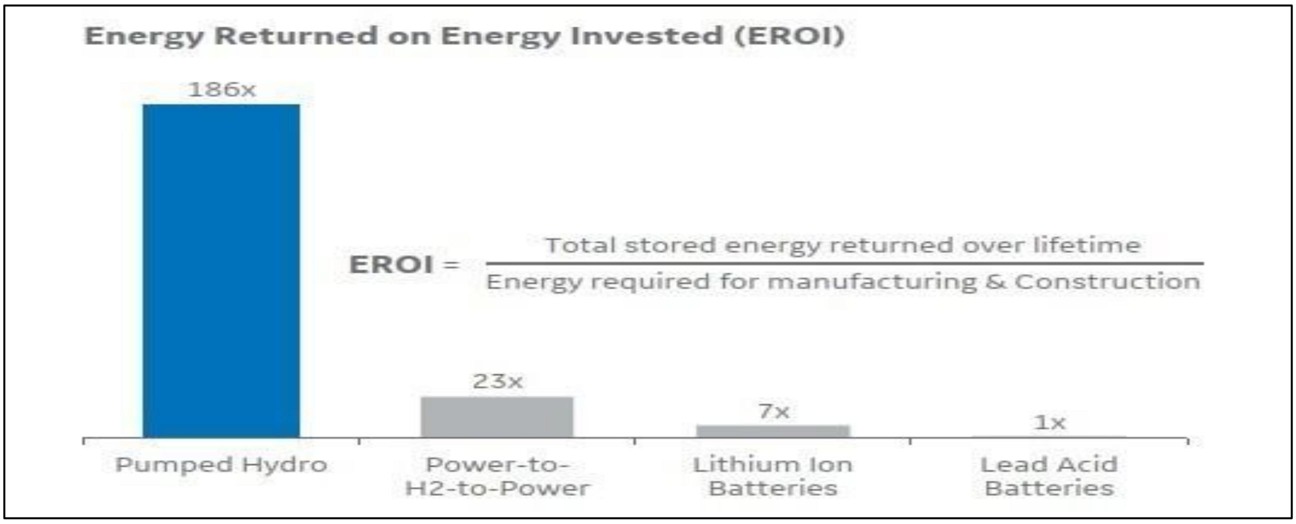
Energy Storage system nomenclature

- When total life cycle costs of storage including replacement, are included, even with cost predictions looking ahead to 2030, PSH is highly competitive as battery systems degrade and periodically need replacing after around 10 years.
- The total cost of PSH is significantly cheaper than of lithium-ion battery systems when accounting for PSH's full lifespan of 80 years and considering storage capacity in the GWh class.
- With a weighted average cost of capital of 6% and an 80-year time horizon, which is a realistic lifetime for PSH, the net present cost of PSH could be 43% lower than lithium-ion batteries for 100 MW and 4h storage duration and 63.5% less for a 1,000W and 10-hour storage system
- The cost of PSH remains below the estimated price of lithium-ion, in 2030, even after taking account of anticipated cost reductions for chemical batteries.

Source – https://www.nrel.gov/docs/fy21osti/78694.pdf

Energy ROI of various Storage technologies

PSH has the highest EROI with 186 times among[13]



- A recent study by Swiss Federal Institute of Technology (ETH) analyzed the "Energy Returned on Energy Invested" of a broad range of power generation and storage technologies.
- This metric measures the energy stored or generated over the life of power generation assets in terms of the energy embedded in their manufacture and construction. Pumped Hydro achieves the highest ratio of the technologies assessed, returning 186 times the energy required for its construction across its operating lifetime.

Comparative analysis of available storage technologies

Presently, two tested available technologies are PHS and BESS.

Table 18: Comparative analysis - PSP vs BESS

Criteria	Pumped hydro system	Battery energy storage system
Hard cost	• PSP where both reservoir needs to be build 7.8 Cr/MW, PSP where one reservoir needs to be build 6.1 Cr/MW	• ~INR 2.90 Cr/MWh including GST
Life	• 35 years to 40 years • Another 35 years to 40 years after renovation modernization	• Depends on cycle time • Battery bank needs to be replaced after every 8-10 Years
Yield	• 75% to 80%	• 68% (Vanadium RF battery storage) • 79% (Lead acid battery) • Upward of 85% (Li Ion)
Levelized cost of storage	• Lower than BESS	• Higher than PHS
Gestation period	• 60 months to 84 months depending upon site	• Less than 24 months
O&M cost	• Higher	• Lower
Aux power consumption	• Lower	• Higher
Disposal concern	• Nil	• High
Overall environmental impact	• Low	• High
Reliance on import	• No	• Currently grid scale system needs to be imported

- Pumped hydro station is better off than that of battery energy storage system in Indian context. However, owing to high gestation period, the project construction needs to start early.

*13 - https://www.ge.com/renewableenergy/sites/default/files/related_documents/GEA34801%20PHS_Development_Australia_WP_R2.pdf, **Image source** – GE report titled "Pumped Hydro Storage in Australia"*

Chapter 4

Identification of PSH projects

4.1. Identification of specific large scale PSP schemes

Table 19: Working in Pumping model

Status of Pump Storage Development on India					
S.No.	Schemes	State	Installed Capacity		Remarks
			No. of Units x Unit size	MW	
A. Schemes Constructed					
a) Working in Pumping Model					
1	Nagarjuna Sagar	Telangana	7 x 100.8	705.6	• Constructed over Krishna river at Nagajuna Sagar • Jointly operated by Andhra Pradesh and Telangana • **Used to meet Peaking Power Demand:** Surplus electricity from the grid being used for pumping the water back to the Nagarjuna Sagar reservoir and recycled for meeting peaking load on daily basis. • **Storage Runtime Capacity:** 700 MW peaking power for 8 hours duration.
2	Srisailam LBPH	Telangana	6 x 150	900	• Constructed over Krishna river at Nagarkurnool District, Telangana and Nandyal District, AP • Operated by Telangana (Left Bank) • **Used to meet Peaking Power Demand:** Surplus thermal power during non peak hours being utilised to pump water back to upper reservoir and meet peak hour demand
3	Kadamparai	Tamil Nadu	4 x 100	400	• Constructed over Kadamparai river basin in Tamil Nadu. • Owned by TNEB and Operated by TANGEDCO • Initially, built to operate both in generation as well as pumping mode to meet states power requirement • **Integration with Solar/Wind Energy:** The PSP has been integrated with Solar and Wind Power plants thus during surplus solar/wind generation it turns into pumping mode and during low solar/wind generation it switches to generation mode. • **Future PSS Use:** As a Frequency Regulator; As a synchronous condenser owing to increase in RE capacity. • **Benefit:** Optimum way to minimise DSM charges, as a test this had been exercised in Feb'18 and the state saved INR 60 Lakhs on DSM • **Can be extended to system operator under ancillary services optimisation**
4	Bhira	Maharashtra	1 x 150	150	• Constructed over Tapi and Tadri rivers • Owned and operated by Tata Power Company Ltd. • **Used to meet additional Day Time Power requirement:** Night time thermal power is used to pump water from lower reservoir to upper reservoir • **Other Advantages that are envisaged:** Spinning reserves; Load swings; Improvement of Thermal Plant Loading; Frequency Control;
5	Ghatgar	Maharashtra	2 x 125	250	• Upper reservoir constructed over tributary of Godavari river and Lower reservoir constructed over tributary of Ulhas river • Owned by Maharashtra Water Resources Department
6	Purulia	West Bengal	4 x 225	900	• Constructed in Ajodhya Hill of Purulia District and water in the reservoir is fed from Kestobazar river • Developed & Owned by NHPC Ltd. And WBSEDCL • **Used to meet peak load demand** of the system and utilize excess available power of the system during off peak time • **Other Major Uses:** Generation; Pumping; Synchronous Condenser and Line Charging (upto 400kV Bus) mode
			Total	3055.6	

Table 20: Presently not working in Pumping mode

Status of Pump Storage Development on India					
S.No.	Schemes	State	Installed Capacity		Remarks
			No. of Units x Unit size	MW	
A. Schemes Constructed					
b) Presently not working in Pumping Mode					
1	Kadana	Gujarat	4 x 60	240	• Constructed over Mahi river in Mahisagar District of Gujarat • Owned and operated by the Gujarat State Electricity Corporation Ltd.
2	Sardar Sarovar Project	Gujarat	6 x 200	1200	• Constructed over Narmada river basin and spread over four major states-Maharashtra, Madhya Pradesh, Gujarat and Rajasthan • Developed and Owned by Sardar Sarovar Narmada Nigam • **Used to meet peak load demand**
			Subtotal	1440	

Table 21: Under active construction and on which construction is held up

Status of Pump Storage Development on India					
S.No.	Schemes	State	Installed Capacity		Remarks
			No. of Units x Unit size	MW	
B. Schemes Under Construction					
a) Under Active Construction					
1	Tehri St- II	Uttarakhand	4 x 250	1000	***Current Status:*** *Likely to be commissioned by 2022-24 (June 23)* • Owned by THDC Ltd. • Once constructed, it is envisaged to meet peaking power requirement, provide balancing load to thermal and renewable generation sources during off peak hours
2	Kundah (Stage I, II, III & IV)	Tamil Nadu	4 x 125	500	***Current Status:*** *Likely to be commissioned by 2022-24 (June 23)* • *Owned by TANGEDCO* • Once constructed, it shall provide peaking power demand of the state
3	Pinnapuram	Andhra Pradesh	4 x 240 and 2 x 120	1200	
	Subtotal			**1400**	
b) On which Construction is held up					
1	Koyna Left Bank	Maharashtra	2 x 40	80	***Current Status:*** *Likely to be commissioned by 2025-26** • *Constructed over Koyna river* • *Owned and being constructed by Maharashtra Water Resource Department* • Once constructed, it shall provide peaking power demand of the state
C. DPR Concurred by CEA					
1	Turga	West Bengal	4 x 250	1000	***Current Status:*** *EC & FC-I obtained. FC-II- awaited* • *Being constructed in the district of Purulia, WB* • *Owned and being constructed by WBSEDCL* • Once constructed, it shall provide peaking power demand of the state

Table 22: Both reservoirs existing

Status of Pump Storage Development on India					
S.No.	Schemes	State	Installed Capacity		Remarks
			No. of Units x Unit size	MW	
E. Schemes under Survey and Investigation					
I. Both Reservoirs Existing					
1	Upper Sileru	Andhra Pradesh	9 x 150	1350	***Current Status:*** *Target date for preparation of DPR - 03/2022* • *Upper reservoir constructed over Sileru river and Lower Reservoir is located on Donkaravi Reservoir* • *Owned and being constructed by APGENCO* • Once constructed, it shall provide peaking power demand of the state
2	Kodayar	Tamil nadu	4 x 125	500	***Current Status:*** *Target date for preparation of DPR - 12/2022* • *Upper reservoir constructed on Kodayar Reservoir and Lower Reservoir is located on PWD's Pechiparaj Reservoir* • *Owned and being constructed by TANGEDCO*
3	Sharavathy	Karnataka	8 x 250	2000	***Current Status:*** *Target date for preparation of DPR - 03/2022* • *Upper reservoir constructed on Talakalale Reservoir and Lower Reservoir is located on Gerusappa Reservoir* • *Owned and being constructed by KPCL* • **Used to meet peak load demand** of the system and utilize excess available power of the system during off peak time
	Subtotal			**3850**	

Table 23: One reservoir existing & one to be constructed

Status of Pump Storage Development on India					
S.No.	Schemes	State	Installed Capacity		Remarks
			No. of Units x Unit size	MW	
E. Schemes under Survey and Investigation					
II. One Reservoir existing & One to be constructed					
1	Upper Kolab	Odisha	2 x 160	320	***Current Status:*** *Target date for preparation of DPR - 12/2022* • *Situated on River Kolab, the Upper reservoir is existing on* Kolab HEP *Reservoir and Lower Reservoir is to be constructed* • *Owned and being constructed by OHPCL*
2	Balimela	Odisha	2 x 250	500	***Current Status:*** *Target date for preparation of DPR - 12/2022* • *Situated on River Kolab, the Upper reservoir is existing on* Balimela HEP *Reservoir and Lower Reservoir is to be constructed* • *Owned and being constructed by OHPCL*
3	Saundatti	Karnataka	(4 x 252)+(2 x 126)	1260	***It is with GE***
4	MP30 Gandhi Sagar	MP	(5 x 240) + (2 x 120)	1440	**E&M package order is with Andriz .**
5	Gandikota	Andhra Pradesh	4 x 250	1000	**Current Status:** Target date for preparation of DPR - 03/2023 • *The Upper Reservoir is proposed off stream and the Lower Reservoir is existing on* Gandikota Reservoir on Penna river • *Owned and being constructed by NREDCAP* • ***Type of PSP:*** *Closed Loop* • **Storage Capacity:** 5 hrs and 23 minutes at 95% availability • Once operational, it shall be put to meet daily peaking power requirements
6	OWK	Andhra Pradesh	4 x 200	800	**Current Status:** Target date for preparation of DPR - 03/2023 • *The Upper Reservoir is proposed off stream and the Lower Reservoir is existing on* Owk Reservoir on Penna river • *Owned and being constructed by NREDCAP* • ***Type of PSP:*** *Closed Loop*
7	Chitravathi	Andhra Pradesh	2 x 250	500	**Current Status:** Target date for preparation of DPR - 03/2023 • The Upper Reservoir is proposed off stream and the Lower Reservoir is existing on Chitravathi Reservoir • Owned and being constructed by NREDCAP • **Type of PSP:** Closed Loop • Once operational, it shall be put to meet daily peaking power requirements
	Subtotal			6420	

Table 24: Both reservoirs to be constructed

Status of Pump Storage Development on India					
S.No.	Schemes	State	Installed Capacity		Remarks
			No. of Units x Unit size	MW	
E. Schemes under Survey and Investigation					
III. Both Reservoirs to be constructed					
1	Sillahalla St- I	Tamil Nadu	4 x 250	1000	**Current Status:** Target date for preparation of DPR - 08/2022 • The Upper reservoir is proposed to be built over Sillahalla river and Lower Reservoir is proposed to be built over Kundah river • Owned and being constructed by TANGEDCO • **Type of PSP:** Open Loop • **Storage Capacity:** 6 hours of run time • Once operational, it shall be put to meet daily peaking power requirements; Integration with Res
2	Warasgaon	Maharashtra	4 x 300	1200	**Current Status:** Target date for preparation of DPR - 12/2022; Construction is likely to commence in 2027 and expected CoD is 2031 • The Upper reservoir is proposed to Mose river and Lower Reservoir is proposed to be built on Kal river • Owned and being constructed by WRD, Maharashtra • **Type of PSP:** Open Loop
3	Kurukutti	Andhra Pradesh	5 x 240	1200	**Current Status:** Target date for preparation of DPR - 03/2023 • The Upper reservoir is proposed on Minor Nallah draining into Boduru Gedda and Lower Reservoir is proposed to be built on Boduru Gedda river • Owned and being constructed by NREDCAP • **Type of PSP:** Closed Loop • **Storage Capacity:** 7 hours of operating time • Once constructed, it shall be used to meet weekly peaking demand (Mon- Sat); Integration with upcoming Res in the state.
4	Karrivalasa	Andhra Pradesh	4 x 250	1000	**Current Status:** Target date for preparation of DPR - 03/2023 ▸Agency-NREDCAP • The Upper reservoir is proposed on Minor Nallah draining into Boduru Gedda and Lower Reservoir is proposed to be built on Boduru Gedda river • Owned and being constructed by NREDCAP • **Type of PSP:** Closed Loop • **Storage Capacity:** 7 hours of operating time • Once constructed, it shall be used to meet weekly peaking demand (Mon- Sat); Integration with upcoming Res in the state.
5	Somasila	Andhra Pradesh	4 x 225	900	**Current Status:** Target date for preparation of DPR - 03/2023 • Both the Upper reservoir and Lower Reservoirs are proposed off stream of river Pennar • Owned and being constructed by NREDCAP • **Type of PSP:** Off River
6	Yerravaram	Andhra Pradesh	3 x 400	1200	**Current Status:** Target date for preparation of DPR - 03/2023 • Both the Upper reservoir and Lower Reservoirs are proposed on Nallah/Stream in the mountain ridges of Dharkonda reserves flowing into the Thandava reservoir. • Owned and being constructed by NREDCAP • **Type of PSP:** Off River
	Subtotal			6500	

Table 25: PFR prepared

Status of Pump Storage Development on India					
S.No.	Schemes	State	Installed Capacity		Remarks
			No. of Units x Unit size	MW	
F. Shemes Under Pre-Feasibility (PFR)/ Priliminary Investigation (PIR) / Detailed Project Report (DPR)					
I. PFR Prepared					
1	Renukaji	HP	10 x 163	1630	• Preliminary Report Prepared in Oct 2021 • Owned and being undertaken by HPPCL
2	Humbarli	Maharshtra	2 x 200	400	• Preliminary Report Prepared in Dec 2019 • Owned and being undertaken by Water Resource Department (WRD)
3	Ghatghar Stage- II	Maharshtra	1 x 125	125	• Preliminary Report Prepared in March 2021 • Owned and being undertaken by Water Resource Department (WRD)
4	Malshej Ghat	Maharshtra	2 x 350	700	• Preliminary Report Prepared in May 2010 • Owned and being undertaken by THDC Ltd.
5	Mutkhel	Maharshtra	1 x 110	110	• Preliminary Report Prepared in May 2010 • Owned and being undertaken by WRD Maharashtra • Likely to commence by 2024; CoD- 2027
6	Chikaldara	Maharshtra	2 x 200	400	PFR prepared in March-2016 Agency- WRD, Maharshtra
7	Varandhghat	Maharshtra	2 x 400	800	• Preliminary Report Prepared in Dec 2016 • Owned and being undertaken by WRD Maharashtra
8	Panshet	Maharshtra	2 x 400	800	• Preliminary Report Prepared in March 2017 • Owned and being undertaken by WRD Maharashtra
9	Nive	Maharshtra	4 x 300	1200	• Preliminary Report Prepared in August 2015 • Owned and being undertaken by WRD Maharashtra
10	Kodali	Maharshtra	2 x 110	220	• Preliminary Report Prepared in April 2014 • Owned and being undertaken by WRD Maharashtra
11	Sinafdar	Bihar	3 x 115	345	• Preliminary Report Prepared in July 2003 • Owned and being undertaken by BHPC (Through NHPC)
12	Panchgotia	Bihar	3 x 75	225	• Preliminary Report Prepared in July 2003 • Owned and being undertaken by BHPC (Through NHPC)
	Subtotal			6955	

Table 26: Under Preparation

Status of Pump Storage Development on India					
S.No.	Schemes	State	Installed Capacity		Remarks
			No. of Units x Unit size	MW	
F. Schemes Under Pre-Feasibility (PFR)/ Preliminary Investigation (PIR) / Detailed Project Report (DPR)					
II. Under Preparation					
1	Velimalai	Tamil nadu	200	200	• Preliminary Feasibility Report under preparation • Owned and being undertaken by TANGEDCO
2	Bandu	WB	4 x 225	900	• Preliminary Feasibility Report under preparation • Owned and being undertaken by WBSEDCL
			Subtotal	1100	

Indication of identified PSP sites to NHPC

Table 27: Indication of identified PSP sites to NHPC

S No	Name of Project	State/UT	Probable IC (MW)	Remarks
1	Matlimarg	J&K	1650	Due to Project not accessible (snow bound), high sedimentation risk and Reservoir topography not matching with CEA Data
2	Ulhas	Maharashtra	1000	Due to R&R issues, private land and development , and Reservoir topography not matching with CEA Data
3	Pinjal	Maharashtra	700	Due to low head and high L/H ratio and upper Reservoir topography not matching with CEA Data
4	Jharlama	Odisha	2500	Due to Inter State issues (lower reservoir is in two states Chhatisgarh), project area falls in wild life sanctuary, Naxal prone area and Reservoir topography not matching with CEA Data
5	Pakwa	Mizoram	1000	Poor geological condition, high sedimentation risk and Reservoir topography not matching with CEA Data and R&R issues
6	Kengadi	Maharashtra	1550	CMD, NHPC vide D.O. letter dated 26.07.2022 has requested Hon'ble Chief Minister, Government of Maharashtra for allotment of 04 nos. PSP site for further studies, Survey & Investigation for preparation of PFR/FR/DPR and implementation if found techno-commercially suitable.
7	Jalond	Maharashtra	2400	
8	Kalu	Maharashtra	1150	Copy of NHPC letters enclosed as Annexure-1. As decided in the meeting, MOP is requested to kindly take up the matter with Water Resources Department Govt. of Maharashtra for allotment of these projects to NHPC.
9	Savitri	Maharashtra	2250	
10	Indirasagar-Omkareshwar	Madhya Pradesh	525	Self Identified -On River- Consent of Govt. of MP for preparation of PFR/DPR has been received on 29.03.200. The PFR of Indirasagar-Omkareshwar Project completed. Levellised tarrif as per PFR is on higher side.
11	Amba	Maharashtra	2500	PFRs under preparation by NTPC. A meeting held with Field Office, WRD, Pune on 19.08.2022. Site visits planned in September 2022 As per JICA Report, 2012, these projects have Environmental issues
12	Madliwadi	Maharashtra	900	
13	Kundi	Maharashtra	600	
14	Tigaleru	Andhra Pradesh	1650	Being pursued with State government for allocation
15	Sandynalla	Tamil Nadu	1200	PFR of these projects prepared by NTPC as consultancy assignment. Site visit completed. Being pursued with State Govt for allocation. Meeting with CMD, TANGEDCO is planned by 31.08.2022.
16	Upper Bhavani	Tamil Nadu	1000	
17	Sigur	Tamil Nadu	1200	
18	Silahalla Stage-II	Tamil Nadu	1000	
19	Netravathy Stage-I	Karnataka	1500	PFR has been prepared by KPCL Site visit is planned in October 2022
20	Tekwa-2	Madhya Pradesh	800	Self Identified -off River- Consent of Govt. of MP for preparation of PFR/DPR has been received on 29.03.200. PFR under preparation to be ready by January'2023
21	Satpura-2	Madhya Pradesh	1000	Self Identified -off River- CMD NHPC vide letter dated 27.06.2022 has requested Chief Secretary, Govt. of Madhya Pradesh for allotment of Satpura-2 PSP site to NHPC for preparation of PFR/DPR. Copy of NHPC letters enclosed as Annexure-2. As decided in the meeting, MOP is requested to kindly take up the matter with Energy and New & Renewable Energy Department, Govt. of Madhya Pradesh for allotment of project to NHPC NHPC has initiated the preparation of PFR which is likely to be completed by January'2023
22	Sinafdar Fall	Bihar	345	CMD NHPC vide letter dated 28.05.2022 has been written to The Hon'ble Member of Parliament, Sh. Mahabali Singh for allotment of the scheme to NHPC Hon'ble Member of Parliament has requested Hon'ble Chief Minister of Bihar vide letter dated 09.07.2022 to direct the concerned department. C opy of NHPC letters enclosed as Annexure-3. As decided in the meeting, MOP is requested to kindly take up the matter with Energy Department, Govt. of Bihar for allotment of projects to NHPC
23	Panchgotia Fall	Bihar	225	
24	Telhar Kund fall	Bihar	1600	
25	Hathiyadah-Durgawati Fall	Bihar	1600	
Subtotal			**31854**	

Identification of specific large scale PSP schemes – Pursued by NHPC

PSP Projects on Joint Venture basis

Table 28: Identification of specific large scale PSP schemes – Pursued by NHPC (JV basis)

S No	Name of Project	State/UT	Probable IC (MW)
1	Lugupahar	Jharkhand	**1500**
2	Panchet Hills	West Bengal	600
Subtotal			2100

Indication of identified PSP sites to THDCIL

Table 29: Indication of identified PSP sites to THDCIL

S No	Name of Project	State/UT	Probable IC (MW)	Remarks
1	Jaspalgarh	Uttarakhand	1935	Discussions were held with state agencies viz. UKID and UJVNL. The project lies within Lal Dhang Reserved Forest Area & Rajaji National park. JV formation between UJVNL and THDCIL is under process.
2	Morawadi	Maharashtra	2320	Site visit conducted. Upper reservoir area is under Koyna Wildlife Sanctuary and Sahyadri Tiger Reserve. The proposed location of upper reservoir is not accessible.
3	Gadgadi	Maharashtra	600	Site visit conducted. Lower dam location is not accessible as it is inside the dense forest. Gadgadi Upper Reservoir site is under Chandoli National Park and Sahyadri Tiger Reserve.
4	Aruna	Maharashtra	1950	Site visit awaited due to heavy rainfall.
5	Kharari	Maharashtra	1050	
6	MalshejGhat	Maharashtra	700	Implementation Agreement could not be signed. It is gathered that on 28th June 2022, an MoU has already been signed between Maharashtra Govt and M/s Adani Green Energy Limited.
7	Humbarli	Maharashtra	400	Survey & Investigation could not be taken up as the project lies in Koyna Wildlife Sanctuary and permission from National Board of Wildlife (NBWL) is required.
8	Nallar	Tamil Nadu	2700	Survey conducted. It is gathered that the major constraint for this project may be the clearance from State Govts as there is interstate water dispute between Tamil Nadu and Kerala. Matter under discussion with State Govt of Tamil Nadu.
9	Idukki	Kerala	300	Meeting held with CMD, KSEBL. A draft MoU in this regard has been submitted to KSEBL on 12.04.2022. KSEBL is in the process of obtaining approval of its Board for proceeding further in the matter.
10	Pallivasal	Kerala	600	
Subtotal			**12555**	

Indication of identified PSP sites to SJVNL

Table 30: Indication of identified PSP sites to SJVNL

S No	Name of Project	State/UT	Probable IC (MW)	Remarks
1	Kolmondapada	Maharashtra	800	Consultant appointed for preparation of PFRs for these four PSPs on 24.05.2022. PFR (Pre-Feasibility Report) are in Progress (Target Completion date-31.10.2022).
2	Jalvara	Maharashtra	2000	
3	Chornai	Maharashtra	2000	
4	TaalKhad	Himachal Pradesh	135	
5	Sidgarh	Maharashtra	1500	The upper and lower reservoir lies within Bheema Shankar Jyotirlinga Wildlife Sanctuary.
6	Baitarni	Maharashtra	1800	The upper and lower reservoir lies within Koyna Wildlife Sanctuary.
7	DaizoLui	Mizoram	2000	Preliminary report studied and site visit planned in August 2022.
8	CheraKhad	Himachal Pradesh	500	Matter regarding allotment of these projects is being taken up with GoHP. GoHP has in-principally agreed to allot these projects to SJVN.
9	Dhurmu	Himachal Pradesh	1600	
10	Purthi and Sach Khas PSP	Himachal Pradesh	190	
11	Sadda	Himachal Pradesh	220	Status not provided
Subtotal			**12745**	

Indication of identified PSP sites to NEEPCO

Table 31: Indication of identified PSP sites to NEEPCO

S No	Name of Project	State/UT	Probable IC (MW)	Remarks
1	Tuivai	Manipur	2100	Unviable considering lesser head, higher dam in poor geology and smaller live storage.
2	Hengtam	Manipur	2250	
3	Khua Lui	Assam	2100	
4	Leiva Lui	Mizoram	2100	Shall be viable with reduced installed capacity. Technical bid for PFR consultancy shall be opened on 01/9/22
5	Nghasih	Mizoram	1250	
6	Mat	Mizoram	1400	Unviable considering close proximity of Thenzwal Town, lesser gross storage.
7	Tuiphai Lui	Mizoram	1650	Viable. Technical bid for PFR consultancy shall be opened on 01/9/22.
8	Tuitho Lui	Mizoram	1050	Located very near to Murlen National Park and therefore, the scheme appears to be not feasible.
9	Panyor	Arunachal Pradesh	660	PFR completed. NOC from the State Govt. awaited.
10	Kopili	Assam	320	
Subtotal			**14880**	

Indication of identified PSP sites to DVC

Table 32: Indication of identified PSP sites to DVC

S No	Name of Project	State/UT	Probable IC (MW)	Remarks
1	Kulbera	West Bengal	1110	CMD, WBSEDCL, West Bengal requested DVC for not carrying out investigation/ study towards preparation of PFR since Govt of West Bengal had identified Kulbera PSP long back and they will prepare PFR for the said PSP.
2	Panchet Hill	West Bengal	600	
3	Lugupahar	Jharkhand	2800	The capacity of the PSP is around 1500 MW after carrying out PFR. Site survey activities is stalled since Aug'2021 due to local resistance Sentiments of local tribal about the "Dharmik Guru" Lugu Baba as Lugu Baba Mandir is situated near the upper reservoir DVC requested for intervention of MoP. JS (Thermal) requested Chief Secretary, Govt. of Jharkhand for necessary guidance
4	Boro	Jharkhand	500	not appear to be technically feasible.
Subtotal			**5010**	

Indication of identified PSP sites to BBMB

Table 33: Indication of identified PSP sites to BBMB

S No	Name of Project	State/UT	Probable IC (MW)	Remarks
1	Majra	Himachal Pradesh	1800	Survey started at site

Overview of the PSP schemes of India at various stages

Status of Pump Storage Development on India					
S.No.	**Schemes**	**IC (MW)**	**Number of existing reservoir**	**Completion in decade 2030/2040**	
Schemes Under Construction					
a) Under Active Construction					
1	Tehri St- II	1000	2	2022-2024	2030
2	Kundah (Stage I, II, III & IV)	500	2	2022-2024	2030
3	Pinnapuram	1200	-		
	Subtotal	**2700**			
b) On which Construction is held up					
1	Koyna Left Bank	80	-	2025-26	2030
c) DPR Concurred by CEA					
1	Turga	1000	-	2029-30	2030
Schemes under Survey and Investigation					
1	Upper Sileru	1350	2	2030-31	2040
2	Kodayar	500	2	2030-31	2040
3	Sharavathy	2000	2	2030-31	2040
4	Upper Kolab	320	1	2031-32	2040
5	Balimela	500	1	2031-32	2040
6	Sundatti	1260	1	2031-32	2040
7	MP30	1440	-	2032-33	2040
8	Gandikota	1000	1	2032-33	2040
9	OWK	800	1	2032-33	2040
10	Chitravathi	500	1	2032-33	2040
11	Sillahalla Stage –I	1000	-	2032-33	2040
12	Warasgaon	1200	-	2032-33	2040
13	Kurukutti	1200	-	2032-33	2040
14	Karrivalasa	1000	-	2032-33	2040
15	Samasila	900	-	2032-33	2040
16	Yerravaram	1200	-	2032-33	2040
	Subtotal	**16170**			
Schemes under PFR/DPR					
1	Renukaji	1630	-	2033-34	2040
2	Humbarli	400	-	2033-34	2040
3	Ghatghar Stage – II	125	-	2033-34	2040
4	Malshej Ghat	700	-	2033-34	2040
5	Mutkhel	110	-	2033-34	2040
6	Chikaldara	400	-	2033-34	2040
7	Varandhghat	800	-	2033-34	2040
8	Panchet	800	-	2033-34	2040
9	Nive	1200	-	2033-34	2040
10	Kodali	220	-	2033-34	2040
11	Sinafdar	345	-	2033-34	2040
12	Panchgotia	225	-	2033-34	2040
13	Velimalai	200	-	2033-34	2040
14	Bandu	900	-	2033-34	2040
	Subtotal	**8055**			

CEA estimates PHS installed capacity of 10 GW by 2029-30. Also, it can be expected that total of 28 GW of capacity be operational by 2040. The above figure is based on the PSP projects identified till date. The Figure may change as more developers are searching off stream PSP projects.

Note: It has been assumed that all identified PSP projects will be in operation by 2040, PSP which is identified in later half of decade 2020 -30 and in 2030-40 will be commissioned by 2050.

4.2. Identification of PSPs for Flexible/ RTC/ Peak Hour Supply

Meeting peaking power demand, grid stability and frequency/ voltage regulations are the few basic inherent characteristics of PSPs owing to which utilities have been investing into this segment. Today, energy storage is the hot cake topic, and this is only because of the rise in RE sources and the fact that RE sources can generate electricity only at some time. Thus, we needed to device some method to maximise our RE benefits.

Energy storage is the answer to it. Today we have several options to store the generated electricity i.e., ranging from pump storage to Flywheels, large scale batteries, etc., the battery storage technology being more of the often talked now. However, in the early days itself, like the water bodies had been identified as conventional source of energy, they have been identified as conventional sources for storing energy by the way of storing downstream flowing water in lower reservoir and then pumping it back to upper reservoir for the generation of additional power.

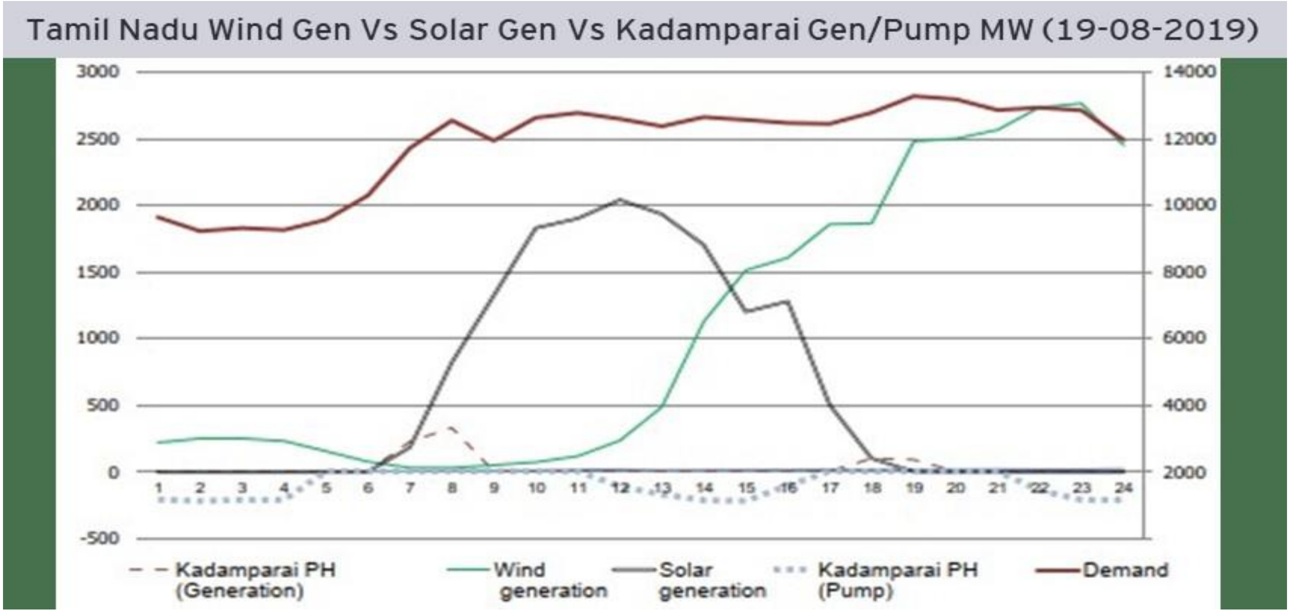


Figure 28: Tamil Nadu wind gen vs solar gen vs Kadamparai gen / pump MW (19-8-19)

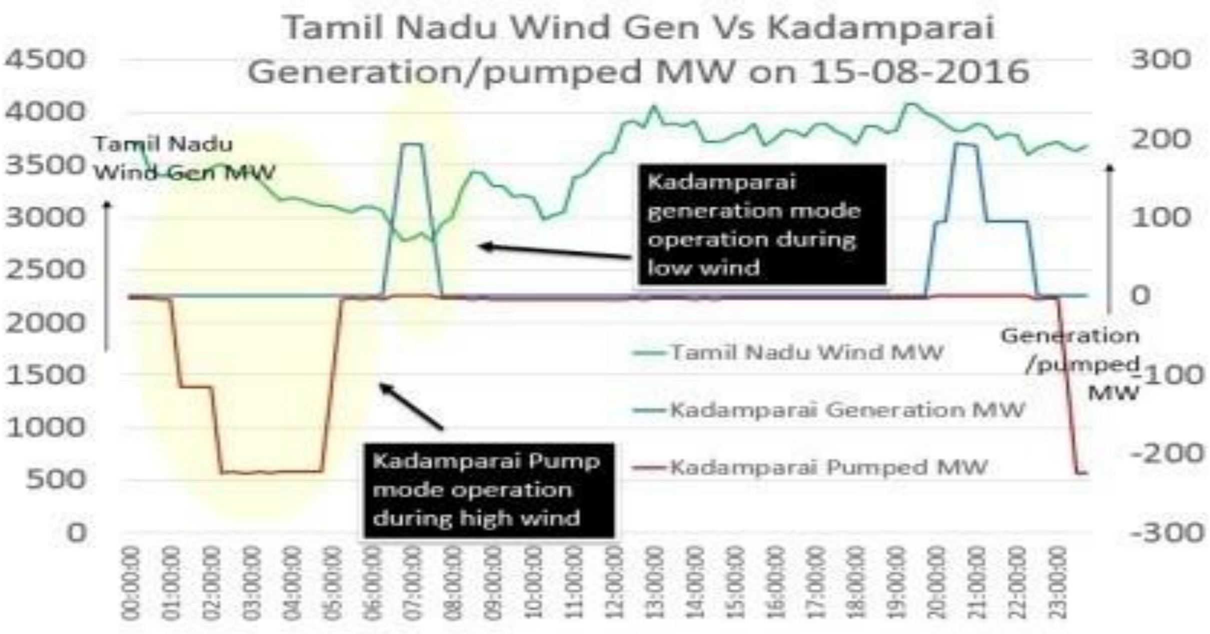


Figure 29: Tamil Nadu wind gen vs solar gen vs Kadamparai gen / pump MW (15-8-16)

Earlier and even today, PSPs were used to meet peaking demand. However, with increased integration of solar and wind capacity's role of PSPs has changed. Now they are actively being used even to regulate voltage and or frequency in the system.
Kadamparai PSP (4 x 100 MW) in Tamil Nadu is one of the best example of it. Its inception came with the idea of meeting peaking power demand. However, with the changing complexities in the grid system its other uses have been well explored and implemented. Firstly, with the advent of Wind Power in the state, Kamaparai PSP was integrated with it to harness the maximum of Wind generation and now it has been again integrated with Wind and Solar capacities.

Future Uses of PSPs

- Varying Operation Mode: Varying operation mode from turbine to pump and vice versa may be envisaged as a future need for PSPs to bring in grid stability as we are moving closer towards 50 Hz frequency limitation and deviation from schedule.
- Frequency Regulator: PSPs can be used as Frequency Regulator in the grid system.
- Synchronous Condenser: With increased integration of RE systems into the grid use of Hydro/PSPs as synchronous condensers can bring-in grid stability.
- Use of PSPs as Ancillary Services.

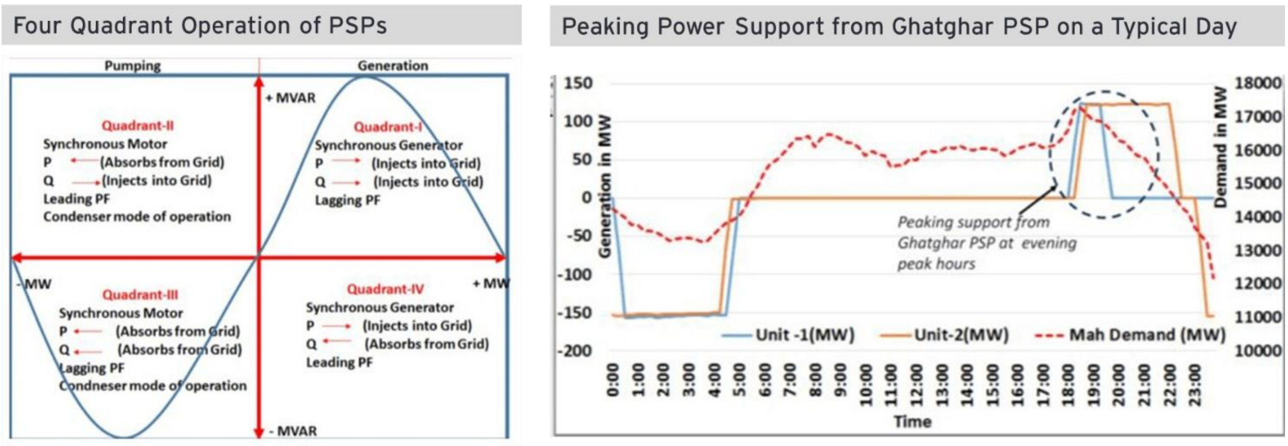


Figure 30: Peak power support from ghatghar PSP[14]

14: POSOCO

Future Uses of PSPs

- Co-Optimization of PSPs: This can be done through roping-in system operators to optimize the energy and ancillary services, wherein some specific control of the plant shall be given to the system operator.
  - **Role of System Operator:** Forecasting and Scheduling of the Plant for generation, pumping and ancillary services shall be done by the System Operator.
  - **Role of PSP Developer:** Works like plant maintenance and operation to be done the developer.

Case Study: Optimisation of Kadamparai PSP

- Plant under Consideration: Kadamparai (4 x 100 MW), Tamil Nadu.
- Month in Consideration: February 2018.
- Objective: To minimize DSM charges.
- Inputs:
  - **Schedules, Actual metered data, and frequency rate from weekly DSM account.**
  - **Kadamparai energy in MU from SRLDC daily report.**
- Constraints considered:
  - **– Ramp up & Ramp down of PSP**
  - **– PSP day energy limit as per operation**
  - **– Max Generation & Max load during pumping**
  - **– Deviation limits with +/-250MW**
- Results: Optimization results shown an extra benefit of ₹ 60 Lakhs to the state.

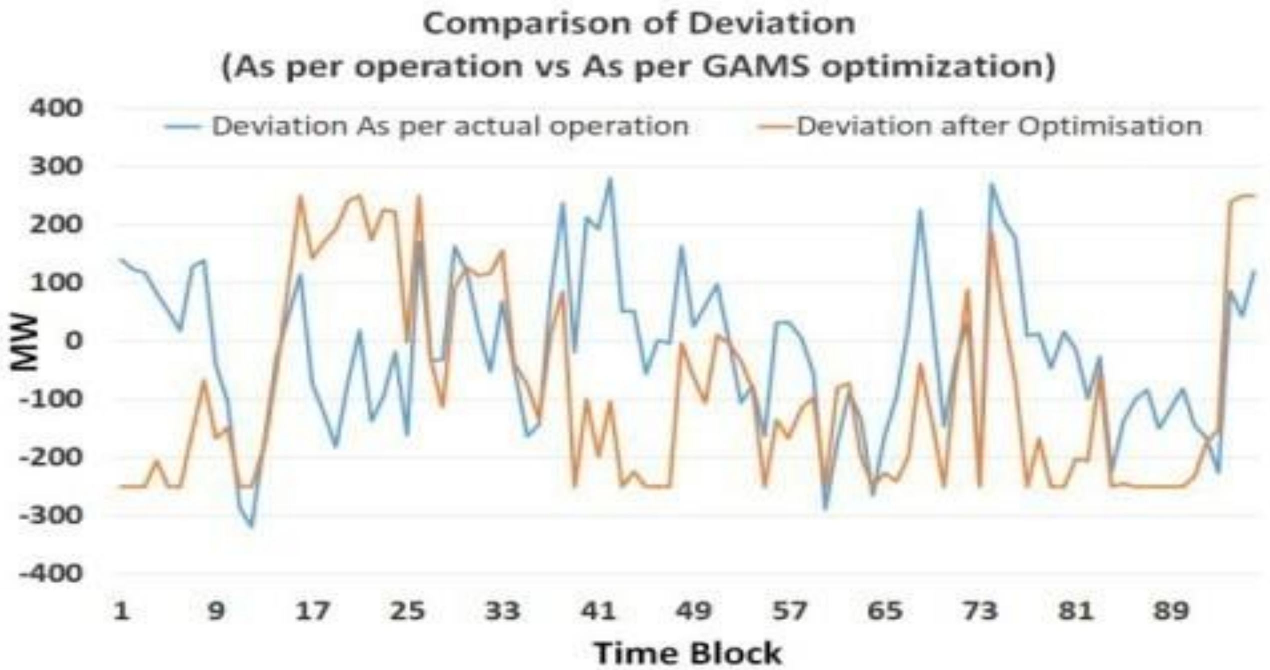


Figure 31: Comparison of deviation (operation vs GAMS optimization)

Chapter 5

Barriers & Challenges

5.1. Revamping the project allotment process

The project allotment process may be transparent and homogenous

Project allotment process–

- The state should clearly define the project allotment process to CPSU, state sector PSU and IPPs.
- State government ideally follows the competitive bidding route for allocating the project. For conducting competitive bidding, a standard bidding document may be developed which may be adopted by different states. The principle of competitive bidding is mentioned in subsequent section.
- However, state shall have the option to allot project on MOU basis. The SOP, application format and allocation criteria for allotting the project on MOU basis should be notified by various states.
- The MOA/allotment agreement may need to homogeneous and concessions to state government shouldn't have a bearing on tariff.
- Moreover, the MOA/allotment agreement should clearly define the milestones and the outcome of not meeting the milestones.

Key elements which may be included in Allotment agreement –

- Projects may be allotted /awarded either on Build Own Operate (BOO) basis. BOOT model may not be prudent for developer as it takes away the benefit of sizeable "Terminal Value" making investment far less attractive.
- Upfront premium should not be charged from developers. It increases the project cost and hence tariff.
- Since it's a storage device and not a generation source, 12% Free Power should not be built in the tariff, if determined on cost plus basis. Further, bidding parameter should also not be Free Power.
- The bidding parameter may be VGF or tariff.
- If the project will be developed under JV route with state government, JV partner need to necessarily bring corresponding share of equity during construction. If the state government agency fails to bring the corresponding equity during construction, then the state government agency won't be a JV partner in the project.

5.2. Barriers & Challenges impacting PSP development and their mitigation

5.2.1. Delays in approvals and clearances

Online form for DPR submission

CEA may prepare a detailed online form for submitting the DPR. Developer(s) need to submit the DPR in the stipulated online format. If there is any information which is not available with the developer, the DPR won't be submitted for concurrence. This will ensure the transparency.

Define maximum turnaround time for every process and sub process

Once the application for a clearance gets submitted, the same can be tracked. Also, the maximum turnaround time for decision may be specified. If application is in accordance with the stipulated guidelines, then clearance may be accorded within specified turnaround time. However, if application is not as per stipulated guideline, then application may be reverted to developer within specified turnaround time.

One stop window for getting clearances

Concept of one stop window for obtaining clearances may also be introduced. In this case, an agency (for e.g., CEA) may be appointed as one stop window. Developer(s) need to apply for all clearances to the specified agency only. The developer need not to interact with any other agency and shall act as a single point of contact for all communication. The appointed agency may interact with other organization.

5.2.2. Land Acquisition and R&R - I

Accountability of state government

Role in land acquisition

- State government should extend its full support in land acquisition. It may be noted that land may be acquired by state government at the cost of developer and allotted developer.
- In case state fails to do so in stipulated timeframe (e.g., 12 months , may be extended by another 6 months), all the delays will be attributed to state government and corresponding pass thru may be allowed. In case, the situation is beyond the reasonable control of state government, it may be classified as "Force Majeure" event. All such event may be explicitly written in hydro policy.

Role in maintaining law and order

- Maintaining law and order of the project premises and enabling infrastructures including dedicated transmission network shall be responsibility of state government. However, safety and security of plant properties and associated premises may come under the ambit of CISF.
- There should be a coordination between CISF and local administration (state government).
- Developer conducts a detailed study on law-and-order requirement for the areas and share the same with local administration (state government) and CISF. Local administration (state government) and CISF team can give a comment on it over a stipulated time period (e.g., 45

days) and propose a security, law, and order plan to developer. Developer needs to revert with their concerns within specified period (e.g., 15 days).

- Local administration (state government) and CISF prepare final blueprint (for their responsibilities and areas respectively) to the satisfaction of developer in next specified period (e.g., 30 days).
- A detailed SOP in accordance with final blueprint needs to be formulated and same needs to be adhered by local administration (state government) and CISF.
- A coordination mechanism governing coordination between CISF team and local administration (state government) needs to be defined and agreed upon by both parties.
- In case of any dispute between CISF and local administration, the same shall be resolved by a committee. The committee shall comprise of five senior officials – two from CISF, two from local administration and one from developer. The designation of the officials may be decided later.

Role of state government

Active cooperation for holding public hearings

- It may be noted that public hearings are conducted for Environment Impact Assessment (EIA) and Forest Rights Act (FRA) 2006. However, cooperation of local administration and state government is discretionary in nature as there is no SOP in place.
- Therefore, a SOP needs to be devised defining the contours of active cooperation of local administration and state government. The local administration needs to gather the public concerns along with the requirement of concerned departments such as SPCB and give due feedback to developer beforehand. This will help developer(s) in chalking out the resolution of the concerns in an appropriate manner.
- The concern state departments shall share its views and hold public hearing within stipulated time frame.
- The maximum turnaround time required from both sides i.e., from developer and from local government / state government needs to be defined.
- Local administration and state government shall also ensure developer meet their commitment and roll out the plan as agreed.
- Similar approach may be followed for SIA and R&R plan consultations.

5.2.3. Project Financing – I

Minimizing IDC

- Interest during construction (IDC) is a function of three important parameters namely – leverage ratio, phasing, and cost of debt. For any project whose expected tariff is going beyond target, option of increasing leverage may be given.
    - As per simulations, increasing the leverage from 70% to 80%, project cost increases by 3.34% owing to increase in IDC. However, levelized tariff decreases by 9.92% as ROE at 16.5% is only charged on 20% of capital. In this case, power cost of later year may be lesser.
- Upfront equity also reduces the IDC; however, it reduces the equity IRR.
- During construction also cheaper source of capital may be brought. Such cheaper source of capital include tax free bonds, proceeds from securitization of future cash etc.
    - For every 1% decrease in interest rate, IDC reduces by ~13.67% and total project cost by ~2.7% and levelized tariff by 3.63%.
    - Developers may monetize their cash generating stations and use the proceeds in development of greenfield projects. However, it may be noted that owing to its peculiarity limited options of asset monetization is possible. One of the successful models are securitization of future cash flows which NHPC has done recently for coupon rate which is attractive than cost of debt. Other option could be selling stakes for limited concession period.
    - It may be noted that other asset monetization options such as Infrastructure Investment Trusts InvIT may not be successful in case of hydro power projects. For any InvIT, to be a success, provided sponsors gives either a pool of cash generating assets or a growth story or both. Since gestation period of hydro projects are relatively high (7-8 years), therefore sponsors cannot commit a growth, hence sponsors need to put a pool of at least 4-5 assets for InvIT. However, if sponsors put more assets under the InvIT route, the cash position in future year gets worsened.
    - Financing may also be done via tax free/ tax saving bonds. The interest rate /coupon rate of these bonds are lower than the conventional loans.

Table 34: Tax free bonds vs tax saving bonds

Tax free bonds	Tax saving bonds
Interest (income) is tax-exempt	Initial investment is tax-exempt
Falls under Section 10 of the Income Tax Act	Falls under Section 80CCF of the Income Tax Act
Offer higher interest rates than tax-saving bonds	Lower interest rates compared to tax-free bonds
The higher maturity period of 10,15 and 20 years	Has a buyback clause -can redeem investments after 5 or 7 years

Reducing interest obligations during operations

Lenders agrees that post commissioning of the project, risk gets reduced significantly and therefore ready to finance the project at lower interest rate. However, tenure of loan may or may not be changed. However, developers need to bear prepayment charges to previous lender(s). RBI may discourage the prepayment charges in case hydro power projects are refinanced. This will reduce the financing charges.

Increasing the repayment period

Increase in repayment period, reduces the rate at which principle gets amortized. Since as per tariff determination methodology, depreciation is considered same as repayment, therefore depreciation amount gets reduced. However, interest outgo gets increased as rate of amortization reduces. The returns also take a hit. By means of illustration, if repayment tenure is increased to 18 years and depreciation is also charged accordingly, levelized tariff gets reduced by ~2%.

Rationalizing interest on working capital

Instead of allowing interest on working capital at normative rate, it may be allowed at actual short-term rate which developer can borrow. However, it may reduce the cash flow to project.

Policy intervention for increasing the availability of capital

Lenders may get tax concessions on the interest charged (till certain rate say MCLR plus 50 bps) against the loan disbursed for the development of hydro power projects. This will act as an incentive for funding hydro power projects.

The Reserve Bank of India has mandated the banks to fix limits on their exposure to specific industry or sectors and has prescribed regulatory limits on banks' exposure to single and group borrowers in India. Further, RBI's prudential exposure norms mandate that a bank exposure to a single borrower should capped to 20% of a lender's tier -I capital base and to 25% limit to a group of connected entities with effect from April 1, 2019. Further banks must classify the sum of all exposures of 10% or above as 'large exposure' and report them to the central bank. **For Hydropower CPSUs/SPSUs the limit of 25% may be extended to 30%.**

VGF

In case the project is awarded via competitive bidding, the bidding criteria can be VGF. There should be a cap on tariff. Bidding document may stipulate project based and bidder may quote VGF. The bidder quoted least VGF may get the project development rights. However, in such cases DPR needs to be prepared by credible party and concurred by CEA upfront. Any change in the scope of the project which has a bearing on the project cost may be bear by developer.

Project development via joint venture

In case the project is either with a state sector company or with any other entity whose credit rating is not so good and facing the issue of equity, project may be developed in joint venture with a relatively healthier company. For example, JV between a PSU (NHPC) and State government owned company such as MAHAGENCO

5.2.4. Financial and Fiscal Incentives for PSPs to ensure commercial viability

GST waiver

- Reduction of GST rate or waiver of GST will reduce the capital cost and hence completion cost and tariff. By means of illustration, a present effective GST rate is 14%, in case project gets GST waiver, the levelized tariff gets reduced by 13.6%. If it brought to the level of Solar Projects i.e., 5%, the levelized tariff gets reduced by 9%.
- Alternatively, partial, or full GST amount may be reimbursed by either state and/or central government.

Waiver of upfront premium

- Upfront premium should not be charged from developers. It increases the project cost and hence tariff.

Waiver of water cess and other state specific taxes

- Since it's not a generation project but an energy storage project, water cess may be discouraged. If at all water cess be applicable the same shall be charged on one time drawl of water and on an annual makeup/losses in the pondage system

Waiving ISTS charges and losses

- Currently, ISTS charges and losses are waived for non-hydro renewable power generations such as solar or wind power projects. If the same is extended for hydro power project, the cost implication for distribution companies for procuring hydro power projects gets reduced by 14% to 19%.

Non applicability of free power and LADF

- Since, it's not an energy generation system but a storage system, therefore free power and LADF should not be applicable in this case. Unlike hydro power project there is input cost i.e., cost of electricity for pumping (charging the storage system).

Tariff sensitivity analysis for PSP where both reservoir needs to be built

We assume LADAF and Free power won't be applicable on PSP

Case study: PSP Bandu - LCOE (INR/kWh) – 7.93

Individual impact	LCOE	Reduction in Tariff (%)
Interest rate decreased by 1%	7.69	3.03%
IoWC (bringing the IoWC to the actual level)	7.89	0.50%
Grant against enabling infrastructure (maximum 1 Cr/MW)	6.55	17.40%
GST wavier (same as renewable) reduce to 5%	6.90	12.99%

Cumulative impact	LCOE	Reduction in Tariff (%)
Interest rate decreased by 1%	7.69	3.03%
IoWC (bringing the IoWC to the actual level)	7.63	3.78%
Grant against enabling infrastructure (maximum 1 Cr/MW)	6.30	20.55%
GST wavier (same as renewable) reduce to 5%	5.48	30.90%

Tariff sensitivity analysis for PSP where both reservoir needs to be built

We assume LADAF and Free power won't be applicable on PSP

Case study: PSP Odisha - LCOE INR/kWh) – 7.76

Individual impact	LCOE	Reduction in Tariff (%)
Interest rate decreased by 1%	7.57	2.45%
IoWC (bringing the IoWC to the actual level)	7.71	0.64%
Grant against enabling infrastructure (maximum 1 Cr/MW)	6.47	16.62%
GST wavier (same as renewable) reduce to 5%	6.76	12.89%

Cumulative impact	LCOE	Reduction in Tariff (%)
Interest rate decreased by 1%	7.57	2.45%
IoWC (bringing the IoWC to the actual level)	7.51	3.22%
Grant against enabling infrastructure (maximum 1 Cr/MW)	6.27	19.20%
GST wavier (same as renewable) reduce to 5%	5.46	29.64%

The sequence is based on the controllable parameters followed by the parameters where concession / assistance from government is required.

5.2.5. Development of a Techno - Commercial Business Model – regulated market

Constructs of techno – commercial business model for regulated market structure is shown below:

Table 35: Constructs of techno – commercial business model for regulated market structure

Construct	Description
Allotment	By allocation/ auction . In case of allocation, mode of tariff determination and power sale arrangement to be specified. In case of auction, tariff is either fixed and winner is decided on VGF or tariff is discovered
Tariff	Static and not linked to dynamic demand and supply scenario of each time block
Input energy	The beneficiary states (discoms) may provide the input energy. Alternatively, the PSP developer may buy input power and charge it from beneficiaries.
Scheduling and dispatch	To be governed by SLDC. The facility may be used for peaking power management at the level of distribution utility.
Applicability	May be applicable in countries where power market is not fully developed.

Advantages

- The problem of missing money does not happen in such cases.
- Can be adopted even if power markets are either absent or not fully developed.

Shortcomings

- The structure may not be economically efficient and follows social cost optimization.
- Optimal usage of the resources may not be possible.

Constructs of techno – commercial business model for liberalized market structure is shown below:

Table 36: Constructs of techno – commercial business model for liberalized market structure

Construct	Description
Allotment	Right to develop the project is with the developer. Developer takes the call basis on market signals. However other clearances from pertinent departments may be required.
Tariff	Depends upon the market. For example in United States, such resources are co-optimized i.e. the project is allowed to recover revenues from different market time frames i.e. DAM, RTM and ancillary services.
Input energy	To be managed by project itself in most of the cases. One of the major source of revenue for the developer is arbitrage in energy cost.
Scheduling and dispatch	To be governed by Independent system operator.
Applicability	May be applicable in countries where power market is fully developed.

Advantages

- The structure is economically efficient and optimal usage of resources is done.

Shortcomings

- The structure may lead to missing money issues specially for new projects.

5.3. Policy & Regulatory Level

5.3.1. Differentiated tariff structure for peak & off-peak load duration & creation and development of ancillary market

Introduction of differential tariff structure for peak and off-peak power supply

- Although Tariff Policy,2016 called for introduction of differential rates of fixed charges for peak and off-peak hours, such provisions are yet to be implemented.
- This would require Time of Day (ToD) metering so that retail tariffs can be differentiated between peak and off-peak durations and such differentials can be reflected in differentiated generation tariffs.
- ToD metering is currently limited primarily to Industrial consumers. With massive, planned deployment of pre-paid smart metering (through multiple programs including the Revamped Distribution Sector Scheme in 2021), a "Time of Day" metering (entailing higher charges during peak hours and lower charges during off peak hrs.) could be implemented across various category of consumers and simultaneously generators supplying power during the peak periods could be provided a higher tariff.

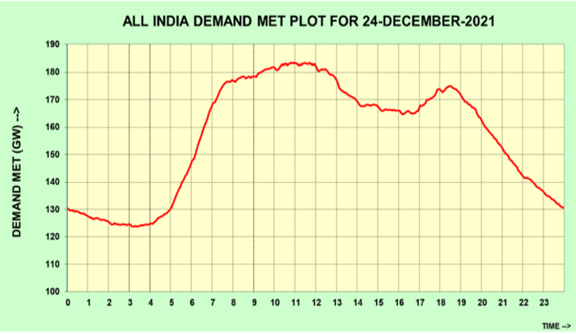
Introduction of the suitable service segments in the Ancillary Market

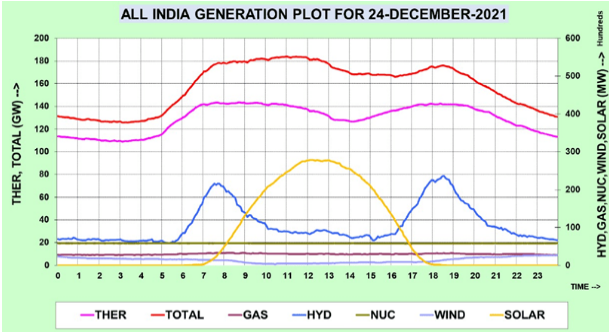
- Ancillary Market is currently maturing in India. The recent (Ancillary Services) Regulations, 2022, published by CERC proposes to introduce market-based procurement of tertiary and secondary reserves ancillary services.
- Introduction of additional services (such as remuneration mechanisms for black start services, reactive services, etc) – as sub-segments – within the ambit of existing services would give more opportunity to hydropower plants to utilize their capabilities like fast ramp-up and ramp-down, start-up and shut-down etc. on the Market Platforms like IEX, PXIL, HPEX etc.

5.3.2. Tariff Optimization Models for bundling of Pumped Storage & Renewable Energy (Solar & Wind) co-located or located in different locations for RTC bidding

- The levelized storage cost of pumped hydro power projects are expected to be in the range of Rs. 8 per kWh.
- On the other hand, assisted by ISTS transmission charges waiver, solar and wind projects have even breached the tariff threshold of Rs. 2 per kWh in recent bids with lowest tariff of Rs. 1.99 per kWh having been discovered by Gujarat Urja Vikas Nigam Limited (GUVNL) for 500 MW solar capacity bid out in December 2020. However, there is an increase in solar tariff owing to changing landscape and rates are expected to be plateaued at INR 2.6/kWh.
- A case for blending and bundling of hydro power with alternate sources has been analysed to have an inherent advantage of reducing the intermittency of RE sources like solar and wind. As illustrated from the monthly report of POSOCO for December 2021, the all-India demand follows a duck curve with two peaks during the day – one peak during day and one peak during evening.

- The supply at all India level from different sources shows the intermittency and limited supply hours of solar power (generation from 7 AM to 6 PM) and wind power (higher generation mainly during night hours)[15].





- The bundled power would offer a lower levelized tariff as compared to standalone hydro power which would enable hydro project developers to bid in future round-the-clock (RTC) and peak-power RE tenders at lower levelized tariffs.
- MNRE had released the guidelines for tariff based competitive bidding for procurement of RTC power from RE projects complemented with power from coal based thermal power projects in July 2020.
- In order to address the concerns linked with RE power like intermittency, limited supply hours, impact of seasonal variation and lower plant load factors, thermal power may be bundled with RE and provide round-the-clock power to DISCOMs.
- The guidelines were amended in November 2020 to apply them to all firm power sources along with thermal, implying thereby that the guidelines shall also be applicable to hydro power.
- Bids invited under these guidelines shall result in identification of cheaper composite power by DISCOMs viz-a-viz procurement cost of standalone RE and standalone thermal or hydro power. As per the guidelines, the RTC power supply should have at least 85% annual availability and also 85% availability during the peak hours. Further, at least 51% of the annual energy should be offered from RE power and remaining from thermal sources.
- The higher hydro tariffs put it at a disadvantage and increase the possibility of hydro power being pushed further down the merit order by the DISCOMs. However, considering the fact that hydro power is also a renewable source of energy albeit with a longer gestation period and the associated societal benefits associated with hydro power as elaborated in the previous chapters, it makes a strong case to be eligible for participation in proposed RTC tenders wherein the specific characteristics of hydro projects may be incorporated to enable purchase of cheaper bundled power by the DISCOMs.

15: POSOCO report December 2021

5.3.3. Other interventions

Storage solutions as grid assets

- There should be clear guideline for maintenance of operating reserves. The demand supply patterns including generation mix needs to be studied on monthly basis and operating reserve requirements needs be updated accordingly.

Remuneration mechanism

- Remuneration mechanism for storage solutions including PSP needs to be aptly devised. There are multiple attempts to value the ancillary services based on multipliers available in developed markets such as US. However, such multipliers may not be used in Indian context as such markets are co-optimized and ancillary services solutions are earing in more than one markets.
- However, Indian power market is yet to achieve the required depth. Therefore, appropriate compensation mechanism may be devised for procuring storage capacity which may give appropriate market signals and developers shall be motivated towards developing capacity.
- Conducting auctions to procure storage capacity (similar to SECI 500MW BESS capacity) may be replicated for pumped storage projects also.

Chapter 6

Conclusion

India in its updated NDC aims to achieve 50 percent of cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 and reduce emission intensity of its GDP by 45% by 2030. This will provide impetus to solar and wind power projects. Due to their intermittent nature, such power projects expose the grid to variabilities. To enhance grid stability and flexibility, India needs to develop energy storage capacities.

In this study, India's storage requirements are estimated for year 2030, 2040 and 2050 which are 50.7 GWh, 1300 GWh and 4097 GWh respectively. To meet the storage requirement of 50.7 GWh by 2030 either 25.35 GW of BESS system needs to be developed or we can opt for 6 hours of PSH of capacity 8.45 GW. To cater to the demand of storage which will reach 4097 GWh by 2050, 682.84 GW of 6 hours of PSH will be required. In the comparative analysis between battery energy storage system and pumped storage system, pumped storage system proves to be more suitable option for the country owing to its lower life cycle cost, no dependency on imports, no needs of preparing a safe disposal plan, lesser environmental impact and a lower levelized cost. Though, pumped hydro station seems better option than BESS in Indian context, the project construction needs to start early due to its high gestation period.

To start with, the project allotment process may be kept transparent and should be homogenous at national level. For allocating the projects, state government should follow the competitive bidding route for which standard bidding document may be developed and adopted. The bidding criteria should be tariff or VGF based instead of free power. States shall have the option to allot project on MOU basis for which the SOP, application format and allocation criteria for allotting the project should be notified by respective states. The MOA/allotment agreement may need to be homogeneous and concessions to state government shouldn't have a bearing on tariff. Moreover, the MOA/allotment agreement should clearly define the milestones and the outcome of not meeting the milestones.

In this study, methods to minimize the time schedule are explored. Such means include submission of online form based DPR, defining maximum turnround time for every process and sub-process, and introducing one stop window for getting clearances. To provide impetus for faster development of pumped hydro storage, there is a need of higher participation of state governments in organizing public hearings, conducting awareness outreach program, acquiring land, preparing, and executing a SOP based law and order maintaining program etc.

There is input cost i.e., cost of electricity for pumping for charging the storage system. To reduce the cost of storage, concessions from state and central government may be required which will improve the saleability of power and increase the viability of the plant. Some of the concessions may include CGST and SGST waiver, including the dedicated transmission line under enabling infrastructure, and waiver of upfront premium. State governments should also consider waiver of water cess and state specific tax. To make 'PSH' lucrative, waiver of ISTS charges may also be considered. Since, it's not an energy generation system but a storage system, therefore free power and LADF should not be applicable in this case.

Developers may also need to adopt innovative means of finance to fund the project to minimize the completed capital cost (CCC). In addition to it, policy interventions are required to increase the availability of capital for hydro power projects. The sector cap may also be relaxed, and lenders may get tax concessions on the interest charged (till certain rate say MCLR plus 50 bps) against the loan disbursed for the development of hydro power projects. These initiatives will act as an incentive for funding hydro power projects.

Ancillary market is maturing in India. CERC has recently published Ancillary Services Regulation, 2022, which proposes market-based procurement of tertiary and secondary reserves ancillary services. Introduction of additional services (such as remuneration mechanisms for black start services, reactive services, etc), which are within the ambit of existing ancillary services will provide more opportunity to hydropower plants to utilize their capabilities like fast ramp-up and ramp-down, start-up and shut-down etc. on the 'market platforms' like IEX, PXIL, HPEX etc. Remuneration mechanism for storage solutions including 'PSH' needs to be aptly devised. There are multiple attempts to value the ancillary services based on multipliers available in developed markets such as US. However, such multipliers may not be applicable in Indian context, as such markets are co-optimized and ancillary services solutions are earing in more than one markets whereas Indian power market is yet to achieve the required depth. Therefore, suitable compensation mechanism may be devised for procuring storage capacity which may give appropriate market signals and developers shall be motivated towards developing the capacity. Conducting auctions to procure storage capacity (like SECI 500MW BESS capacity) may be replicated for pumped storage projects.

India's rapid transition towards self-reliance in its energy needs without undermining the commitments it has made towards climate change, will require impetus in developing pumped storage systems capacities.