Chapter 18
Levelized Cost of Sustainable Electricity Production and Storage in India

Asif Pervez, Jahangir Chauhan, and Irfan Ali

Abstract This study examines various technical and financial determinants of levelized cost of electricity production and storage in India based on different technologies. Descriptive research design is adopted in this study. Data are obtained from reports of the Central Electricity Authority (C.E.A.), Central Electricity Regulatory Commission (CERC), Government of India and India stats database. Raw data are analysed and have been presented using tables and figures. The study's findings show significant reductions in LCOE of Solar P.V. and LCOS of battery between 2021 and 22 and 2029 and 30. It was concluded that the conventional and non-conventional energy system could be combined in hybrid energy systems with battery storage and pumped storage to supply consumer energy demands consistently.

Keywords Levelized cost of electricity · Battery storage · Pumped storage · Conventional and non-conventional energy sources · India

1 Introduction

Electricity is crucial for the development of an economy, especially an emerging economy like India. Inaccessibility to electricity is a significant challenge for a country's social and economic progress (Dinkelman 2011; Stern et al. 2019). Despite being the seventh-largest economy of the world in 2018, India has a meagre per capita electricity consumption of 1122 kWh in 2017 compared to many other developed and developing nations globally. Although various reforms were initiated after 1991

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and by Electricity Act 2003, the Indian electricity system's financial health is still an area of concern (Agrawal et al. 2017). The problem of India's power sector and its prospect has been studied and documented in Bhattacharyya (1994), where it is asserted that there are widespread energy shortages due to the high demand for electricity that outstripped the supply. The 7th Sustainable development Goal (SDGs) of the United Nations is determined to give sustainable and clean energy for the social and economic development of all (United Nation 2015). Economic growth and energy-related issues for developing nations under the SDGs have been studied and documented in (Nomani et al. 2017, Gupta et al. 2018, Ali et al. 2020, and Modibbo et al. 2020). A developing nation's energy policy should aim to provide uninterrupted energy in a reasonable, just, efficient, and environmentally caring manner (Narula 2014). The initiatives for India's renewable energy sector under 'National action plan on climate change' has been intensively reviewed by Chandel et al. (2016), according to them, the power sector contributes about half of the total carbon emission in the world due to its fast fossil fuels depletion. India in its Intended Nationally Determined Contribution to UNFCCC intended to reduce the carbon emissions by 33–35% and to increase non-fossil fuel-based electric power installed capacity up to 40% of total installed capacity by 2030 (UNFCCC 2015). Therefore, the Government of India needed to promote renewable energy. The government has declared a target for installing 175GW of renewable energy capacity by 2022 (Government of India 2015) and an installed capacity of 275 GW by 2026–27 (CEA 2018). However, the likelihood of adverse environmental effects of India's renewable energy sources have studied Abbasi and Abbasi (2000), and they concluded that the impact could be as strongly negative as compared to the conventional sources of energy.

The current status of solar power policies has studied by Rathore et al. (2019), and the motivating factors for investing in solar rooftop PV also analysed and finally, a summary of barriers to the solar rooftop PV growth and development are provided. Central Electricity Authority has also considered grid battery storage and pumped storage in their optimal generation mix for 2029–3 (CEA 2018) to complement Renewable Energy generation. The cost of battery energy storage systems has been decreasing with advancements in technology, and it may help absorb more Renewable Energy into the electricity system. Therefore, the conventional and non-conventional energy systems could be combined in hybrid energy systems with battery storage and pumped storage to supply consumer energy demand consistently; (see Fig. 1).

1.1 Current Scenario of the Electricity Sector in India

Total Installed Capacity of electricity in India as on 31.01.2019 was 349,288.2 MW, which comprises of 45,399.2 MW from Hydro, 223,027.34 MW from Thermal, 74,081.66 MW from R.E.S, and 6780 MW from Nuclear (CSO 2019).

Figure 2 shows the installed capacity of different sources from 2009 to 2019. India's electricity sector has been traditionally dominated by a thermal and hydro

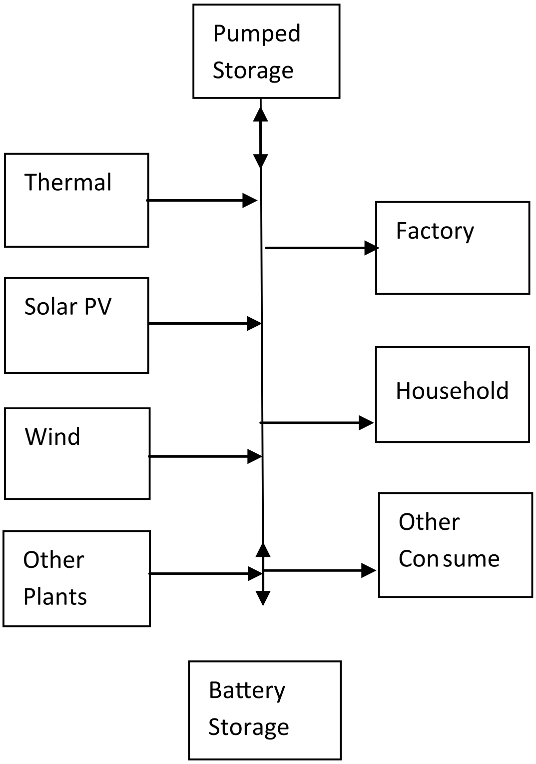
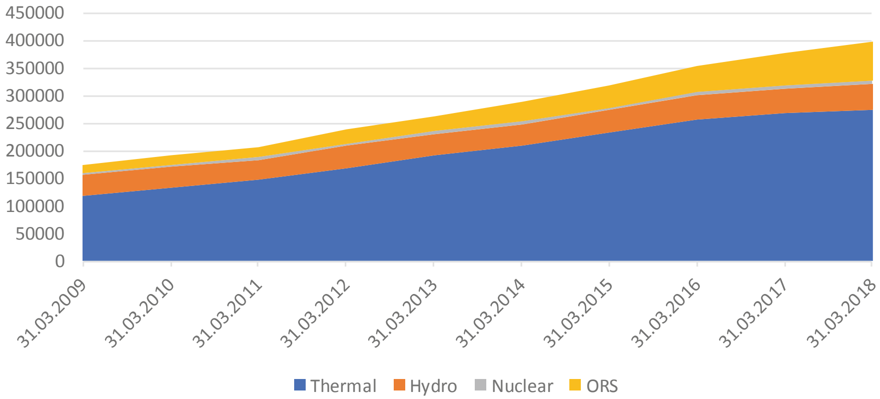
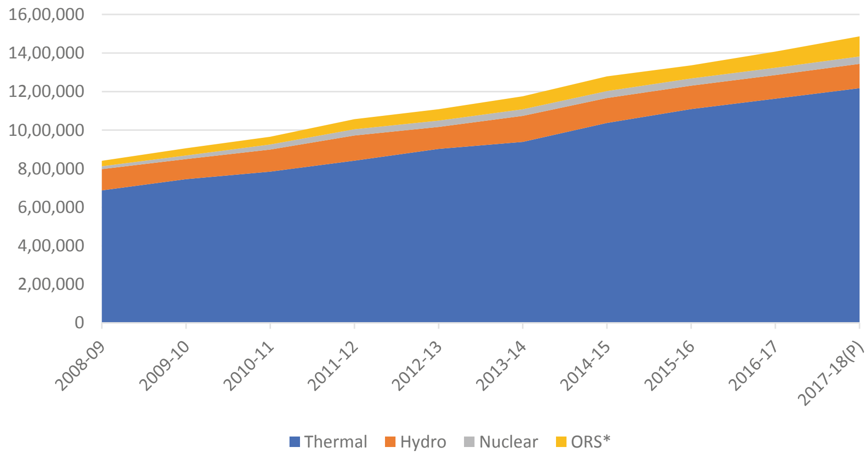


Fig. 1 Hybrid electricity system with storage



* *ORS means Other Renewable Sources*

Fig. 2 Installed electricity generation capacity of different sources



(P)-Provisional
** ORS means Other Renewable Sources*

Fig. 3 Generation of electricity from different sources

generation with electricity generation of 77% and 10.7%, respectively, during 2018–19. Other renewable sources, such as small hydro, solar, wind, and biomass, account for 9.3% of the total generation and nuclear account for 2.7% of total generation. Figure 3 shows the electricity generation from different sources from 2009 to 2019 (CEA 2019).

2 Methodology

Based on the available technology and cost parameters, LCOE and LCOS estimations are made based on LCOE Formula as given in Eq. (1). Simultaneously, the LCOS form is developed in analogy to the Levelized Cost Energy formulation where the fuel cost has been replaced by charging cost and generation electricity has been replaced by the discharged electricity as given in Eq. (2) (Belderbos et al. 2016). Formulation of the Levelized Cost pumped storage (LCOEps) is developed in analogy to the Levelized Cost Energy formulation where the fuel cost has been replaced by pumping cost as given in Eq. (3) (Abdellatif et al. 2018).

$$\text{Levelizsed cost of energy (LCOE)} = \frac{\sum\left[\frac{(I_t + OM_t + F_t)}{(1+r)^t}\right]}{\sum\left[\frac{E_t}{(1+r)^t}\right]} \quad (1)$$

$$\text{Levelizsed cost of storage (LCOS)} = \frac{\sum\left[\frac{(I_t+OM_t+C_t)}{(1+r)^t}\right]}{\sum\left[\frac{DE_t}{(1+r)^t}\right]} \quad (2)$$

$$\text{Levelizsed cost of pumped storage plant (LCOEps)} = \frac{\sum\left[\frac{(I_t+OM_t+P_t)}{(1+r)^t}\right]}{\sum\left[\frac{E_t}{(1+r)^t}\right]} \quad (3)$$

where symbols used in the Eqs. (1) to (3) have their usual definitions that is $\boldsymbol{I_t}$ is the initial investment (Capital cost), $\boldsymbol{OM_t}$ is the operating and maintenance costs, $\boldsymbol{F_t}$ is the fuel cost, $\boldsymbol{C_t}$ is the battery charging cost, $\boldsymbol{P_t}$ is the pumping cost, $\mathrm{E_t}$ is the system energy yield, $\boldsymbol{DE_t}$ is the discharged electricity, $\boldsymbol{t}$ is number of years, and $\boldsymbol{r}$ is for a discount rate.

3 Levelized Cost of Electricity

In this section, cost parameters, technical parameters, and the levelized cost of conventional and non-conventional sources have been given in Tables 1, 2, 3, 4, 5 and 6.

Table 1 Cost parameters of conventional sources of electricity

Technology	Hydro	Coal (Pithead)	Coal (Load Centred)	Gas	Nuclear (LRW)	Nuclear (PHWR)	References
Capital Cost(Lakh/MW)	1170	785	760	523	1900	1170	CSO (2019),CERC (2014)
Operation & maintenance (Lakh/MW)	29.25	18	18	28.61	20	20	CSO (2019)
Fuel cost (Rs/Kwh)	0	2.59	2.59	2.70	0.85	0.85	CSO (2019)
Escalation of O&M (%)	3	3	3	3	3	3	Assumed
Escalation of fuel cost per year (%)	0	2.5	2.5	2	0	0	CSO (2019)

Table 2 Technical parameters of conventional sources of electricity

Technology	Hydro	Coal (Pithead)	Coal (Load Centred)	Gas	Nuclear (LRW)	Nuclear (PHWR)	References
Construction time (Years)	8	4	4	4	6	6	CSO (2019)
Plant life (Years)	35	25	25	25	30	30	CSO (2019)
PLF/CUF (%)	35	60	60	30	68	68	CSO (2019), Instat (2019)
Auxiliary consumption (%)	0.7	6.5	6.5	2.5	10	10	CSO (2019)

Table 3 LCOE of conventional sources of electricity

Technology	Hydro	Coal (Pithead)	Coal (Load Centred)	Gas	Nuclear (LRW)	Nuclear (PHWR)
LCOE (Rs/Kwh)	4.64	5.40	5.35	5.96	4.77	3.48

Table 4 Cost parameters of non-conventional sources of electricity

Technology	Solar PV	Wind	Biomass	Small hydro	References
Capital Cost(Lakh/MW)	450	600	570	760	CSO (2019)
Operation & maintenance(Lakh/MW)	5.625	6	11.4	19	CSO (2019)
Fuel cost (Rs/Kwh)	0	0	7	0	CSO (2019)
Escalation of O&M (%)	3	3	3	3	Assumed
Escalation of fuel cost per year (%)	0	0	2	0	CSO (2019)

Table 5 Technical parameters of non-conventional sources of electricity

Technology	Solar PV	Wind	Biomass	Small hydro	References
Construction time (Years)	0.5	1.5	3	5	CSO (2019))
Plant life (Years)	25	25	20	35	CSO (2019)
PLF/CUF (%)	19	29	30	45	
Auxiliary consumption (%)	1	0.5	8	0.7	CSO (2019)

Table 6 LCOE of non-conventional sources of electricity

Technology	Solar PV	Wind	Biomass	Small hydro
LCOE (Rs/Kwh)	2.98	2.52	11.70	2.34

3.1 Cost and Technical Parameters of Conventional Sources

Thermal electricity sources have the highest LCOE among the conventional electricity sources, followed by nuclear and hydro. However, Nuclear (PHWR) has a low LCOE. This high LCOE of thermal indicates low Plant load Factor, increase in the cost of coal, and high operating and maintenance cost.

3.2 Cost and Technical Parameters of Non-Conventional Sources

Biomass sources have the highest LCOE among the non-conventional sources, followed by solar, wind, and small hydro. High LCOE of Biomass results from low Plant load factor (30%) due to non-availability of fuel and high cost of baggage. At the same time, lower LCOE of solar and wind is due to an increase in their Plant load Factor, improvement in the technology, and a decrease in the solar panel cost.

Figure 4 shows a reduction in LCOE of solar PV plants as Capital costs of solar plants is expected to reduce from Rs 4.5 Crores in 2021–22 to Rs 4.1 Crores in the year 2029–30 (CSO 2019). Therefore, levelized cost of solar is expected to decrease from Rs 2.99 per kwh in 2021–22 to 2.76 in 2029–30, other factors assuming to be constant. Figure 5 depicted LCOE of solar PV plants at different capacity utilization factor as CUF of solar PV is expected to increase in coming years. Levelized cost of solar is expected to reduce from Rs 2.99 per Kwh in 2021–22 at 19% CUF to 1.89 at 30% CUF, other factors assuming to be constant.

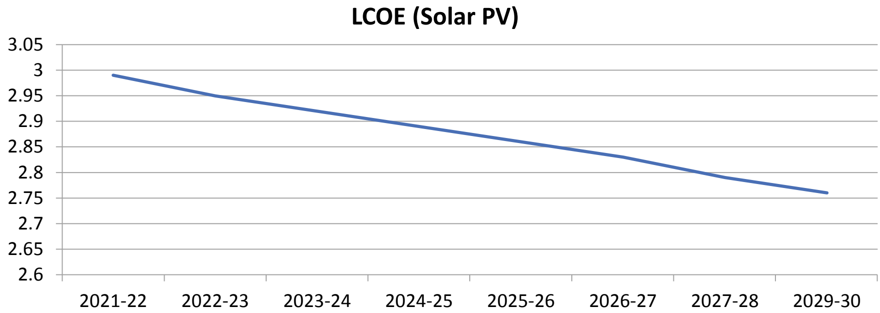


Fig. 4 Projected levelized cost of electricity production from solar PV

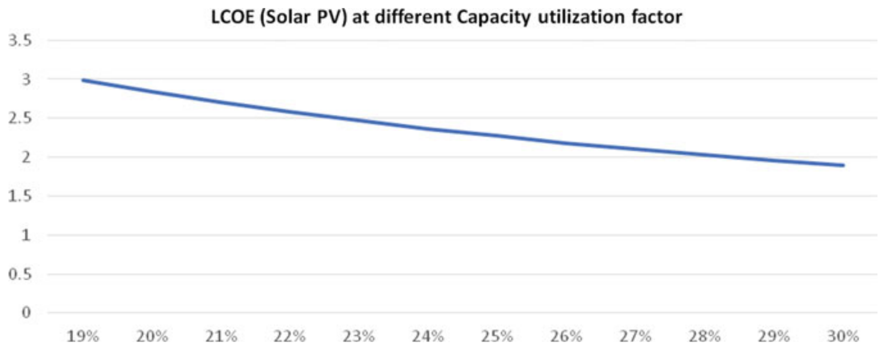


Fig. 5 LCOE (Solar PV) at different Capacity utilization factor

4 Levelized Cost of Energy Storage

In this section, the levelized cost of battery storage and pumped hydro storage have been calculated and discussed.

4.1 Battery Storage

In Table 7, assuming number of cycles (charging/discharging events) as 365, a life of 10 years, a battery storage degradation rate of 1% per year (Comello and Reichelstein 2019) a 9% cost of capital, an 85% round-trip efficiency, the corresponding Levelized cost of storage is Rs 9.36 per kWh for 2021–22. The cost of battery energy storage is taken as ₹7 Cr/ in 2021–22 and is expected to reduce to ₹4.3 Cr/MW in 2029–30. A uniform reduction in initial battery cost has been assumed for the present study. Figure 5 shows the LCOS of battery is expected to reduce from Rs 9.36/kWh in 2021–22 to 6.24 in 2029–30, considering other technical factors to remain constant (Fig. 6).

4.2 Levelized Cost of Electricity from Pumped Hydro Storage (PHS)

PHS is crucial for India's commitments for 275 GW renewable energy installation by 2027. Around 2612 MW of PHS is working in the country, and another 3145 MW is under construction. For further progress and exploiting the potential of PHS, at least US $20 billion of investment is required in the coming years (Buckley and Shah 2019). Pumping cost is the cost of electricity that is used to lift up water from the lower reservoir to the upper reservoir during off-peak times. The pumping cost is assumed

Table 7 Cost and technical parameters for battery storage

Parameters	Battery storage	References
Installed power storage (MW)	1.0	
Initial investment (Rs Lakh/MW)	700	CSO (2019)
Operating & Maintenance (Rs lakh/MW)	2%	CSO (2019)
Charging cost (Rs/Kwh)	0	Assumed
Utilization of usable storage capacity	100%	CSO (2019)
Number of cycle per year	365	Comello and Reichelstein (2019)
Degradation in storage capacity	1%	Comello and Reichelstein (2019)
Auxiliary consumption	12%	CSO (2019)
Round trip efficiency	88%	Assumed
Residual value (Rs Lakh/MW)	0	Assumed
Construction time (Years)	0.5	CSO (2019)
Depth of discharge	100%	Assumed
Life (years)	10	CSO (2019)
Discount rate	9%	CSO (2019)
LCOS (Rs/Kwh)	9.36	Calculated

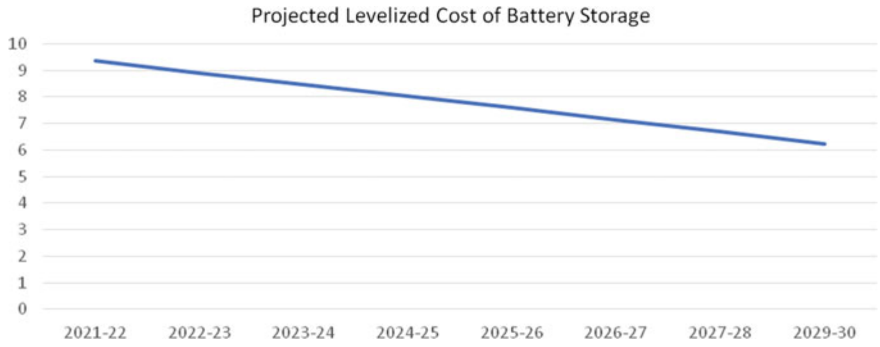


Fig. 6 Projected levelized cost of battery storage

Table 8 Cost and technical parameters of pumped storage plant

Parameters	Pumped storage	References
Capital Cost(Rs Lakh/MW)	1287	CSO (2019)
Operation & maintenance (In Percentage)	2.5	CSO (2019)
Pumping Cost (Rs/Kwh)	0	Assumed
Construction Time (Years)	8	CSO (2019)
Plant Life (Years)	35	CSO (2019)
PLF/CUF (In percentage)	35	
Auxiliary consumption (In percentage)	0.7	CSO (2019)
Round trip efficiency (In percentage)	75	Abdellatif et al. (2018)
Discount rate (In percentage)	9	CSO (2019)
LCOE (Rs/Kwh)	7.51	Calculated

to be zero for the present study understanding supplying electricity for pumping from grid-connected renewable power plants not generating electricity during peak times or the spinning reserve of thermal power plants during the off-peak time (Abdellatif et al. 2018). The corresponding levelized cost of energy for PHS is 7.51 Rs /Kwh (Table 8).

5 Conclusion and Recommendations

Levelized cost of electricity production and storage in India based on different technologies indicates significant reductions in LCOE of Solar PV and LCOS of battery between 2021 and 22 and 2029 and 30. Currently, Biomass sources have the highest LCOE among the non-conventional sources of electricity due to low Plant load factor (30%) due to non-availability of fuel and high cost of bagasse. Simultaneously, LCOE of solar and the wind is expected to get reduced further due to the increase in their Plant load Factor, improvement in the technology and decrease in the cost of solar panel and wind plant. PHS is crucial for India's commitments for renewable energy installation by 2027. However, The corresponding levelized cost of energy for PHS is high. The conventional and non-conventional energy system could be combined in hybrid energy systems with battery storage and pumped storage to consistently supply consumer energy demands. Policymakers should analyse different pathways oriented to the sustainable development of electricity system while developing a cost optimization model for the electricity system integrating renewable energy sources and electricity storage system and developing strategies for achieving SDGs related to clean electricity production.

Declaration of Interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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