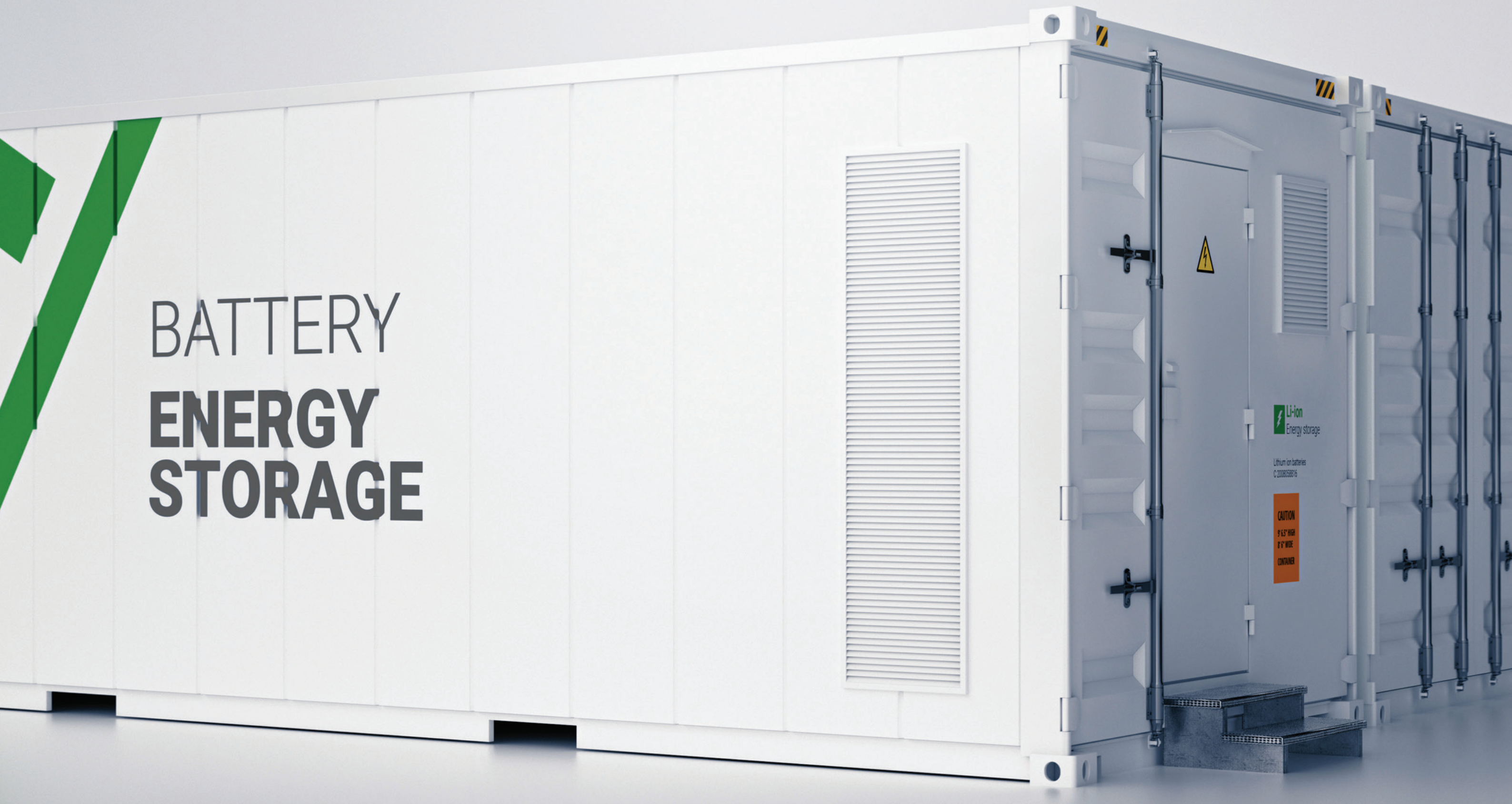
BATTERY ENERGY STORAGE SYSTEMS AS AN ALTERNATIVE TO DIESEL GENERATORS

A COMPARATIVE COST ANALYSIS FOR TAMIL NADU

AUGUST 2022

AurovilleConsulting



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ACKNOWLEDGMENT

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ACRONYMS

BESS	Battery Energy Storage Systems
BtM	Behind-the-Meter
CAPEX	Capital Expenditure
C&I	Commercial and Industrial
CO2e	Carbon dioxide equivalent
CPCB	Central Pollution Control Board
DALY	Disability-Adjusted Life Years
DG set	Diesel Generator set
EV	Electric Vehicles
FtM	Front-of-the-Meter
GW	Giga Watt
GWh	Giga Watt-hour
HT	High Tension
IHME	Institute for Health Metrics and Evaluation
INR	Indian Rupee
kVA	Kilo Volt Ampere
kW	Kilo Watt
kWh	Kilo Watt-hour
LCOE	Levelized Cost of Energy
LCOS	Levelized Cost of Storage
Li-ion	Lithium-ion
MSME	Micro, Small, Medium Enterprise
NOx	Nitrogen Oxide
OPEX	Operational Expenditure
PM	Particulate Matter
RE	Renewable Energy
RECD	Retro-fit Emission Control Device
Solar PV	Solar Photovoltaics
SOx	Sulphur oxide
TNPCB	Tamil Nadu Pollution Control Board
UPS	Uninterruptible Power Supply

KEY FINDINGS

The Levelized Cost of Energy (LCOE) of a diesel generator (DG) set and the Levelized Cost of Storage (LCOS) of a lithium ion (Li-ion)-based Battery Energy Storage System (BESS) were compared for different hours of autonomy or back-up while considering a range of capital costs. The results indicate that the LCOE of DG sets varies between INR 49.58/kWh to INR 57.63/kWh. The LCOS of BESSs, when charged at a solar tariff of INR 3.95/kWh, varies between INR 39.71-61.72/kWh, when charged at an industrial tariff of INR 6.67/kWh, it varies between INR 43.71-65.71/kWh, and when charged at a commercial tariff of INR 8.40/kWh, it varies between INR 46.25-68.25/kWh. The LCOE of the DG set is found to be most vulnerable to diesel prices, while the LCOS of the BESS is largely dictated by the market prices of the Li-ion battery packs.

When considering the average capital costs of both back-up systems, the analysis indicates that the per unit cost of energy from a BESS charged at the solar tariff is the most economical option for all hours of autonomy. The per unit cost of DG is less in comparison to the per unit cost of BESS when charged from the grid at the industrial and commercial tariff, for all hours of autonomy or back-up. However, further analysis indicated that were the generator subsidy scheme (currently available in Tamil Nadu) transferred from DG sets to BESSs, the latter can become a more economical back-up option even when charged from the grid.

In addition to the economic evaluation, the BESS and DG were also assessed in terms of externalities. Both technologies have different emission profiles and emission points, which include air pollutants and greenhouse gases. Emission levels for BESS varied depending on the source of electricity used to charge the system.

In conclusion, the per unit cost of BESS charged with solar was found financially most attractive across all simulated autonomy ranges. This technology proposition also provides the cleanest form of backup power since no emissions are generated during power generation.

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01 BACKGROUND

Power demand across the country is growing, and meeting peak demand is becoming more challenging. In Tamil Nadu, frequent power outages are observed, especially during summer months (Ramesh, 2019). This has an impact on the State's economic performance. A World Bank study identified power outages as one of the main barriers to economic growth in South Asian countries, the study estimated that providing uninterrupted electricity supply would increase the profits of businesses in India by USD 22.70 billion a year (Zhang, 2019).

To reduce economic impacts of unreliable power supply, commercial and industrial (C&I) entities undertake investments in power backup systems. The most commonly used systems are diesel generator sets (DG sets) and battery energy storage systems (BESS), also known as an uninterruptible power supply (UPS).

DG sets have been a convenient power backup option due to an established market, their reliability, affordability, and modularity. In 2019-20, DG sets with a total aggregate capacity of more than 5,500 MVA were sold to C&I consumers in India (Raja, 2020)[1]. Currently, DG sets are incentivized by the Tamil Nadu Government through capital subsidies for manufacturing Medium, Small, and Micro Enterprises (MSMEs) (Government of Tamil Nadu, 2017). However, DG sets have a high environmental footprint, cause noise pollution and negatively impact human health. To tackle the former problem, tighter emission norms, such as the requirement to implement a retro-fit emission control device (RECD) or scrap old DG sets (older than 15 years) are being mandated by the Tamil Nadu Pollution Control Board (TNPCB), (TNPCB, 2021) and this has cost implications for the end user.

On the other hand, BESS could operate on zero emissions, if charged from renewable energy sources, and with minimal noise pollution. And with no exhaust emissions, BESSs are particularly helpful in urban areas. Additionally, in recent years Li-ion batteries have observed a dramatic drop in cost of 89% over the years 2010-2020 (Bowen, T., and Gokhale-Welch, C., 2021). This could facilitate India's market for stationary storage, which is expected to increase to 30 GWh by 2027 from 25 GWh as of 2020 (Smart Energy International, 2021).

Apart from performing their primary function as a power backup, BESSs can also provide grid services such as load shifting, load following, peak load management, voltage, and frequency support and facilitate higher levels of renewable energy integration.

This report compares the economic and environmental performance of a Li-ion-based BESS with a conventional DG set, as power backup solutions. A load for C&I entity is assumed and four different scenarios - based on the fuel cost and different electricity tariffs in Tamil Nadu - are analyzed (refer to Table 1). The figures of merit include the levelized cost of generation (LCOE) for the DG set and the levelized cost for storage (LCOS) for the BESS. Further, the air and greenhouse gas emissions associated with each scenario are analyzed. We hope that this report will assist C&I entities in Tamil Nadu to make the most economic and environmentally sound investment in their power backup systems.

[1] As a comparison, the total solar energy capacity addition in India in the year 2019 stood at 7,345 MW (The Economic Times, 2020).

Table 1: Scenarios

No	Scenarios
1	DG set
2	BESS charged at industrial grid tariff
3	BESS charged at commercial grid tariff
4	BESS charged at solar tariff

02 METHODOLOGY AND KEY ASSUMPTIONS

A financial and emissions analysis was carried out for the DG set and Li-ion-based BESS. For the financial analysis of DG sets, the LCOE is calculated. LCOE can be described as the average cost per unit (kWh) expressed in the present value[2]. The LCOE determination process considers all the cash outflows (such as capital, operational and maintenance, and fuel expenditure) and all the cash inflows over the system's lifetime. In the case of the BESS, an LCOS analysis was used to evaluate the cost of energy. The LCOS is analogous to the LCOE (Unni et al., 2022), and is used in the context of energy storage systems.

The LCOE and LCOS values can be used as a performance index for the back-up technologies. The values have been calculated using the tool 'Levelized Cost Calculator for Distributed Energy Resources V3.0' (Auroville Consulting, 2022). The BESS and the DG set were sized to meet an assumed critical load of 95 kW till the end of their lifetime. The critical load refers to the baseload or electrical load that the consumer requires to be running at all times. (Additionally, no escalation in load with time was assumed). Considering an annual capacity degradation factor of 2% for both the back-up systems over their lifetimes, the DG set was sized to 128 kW capacity and the BESS was sized to 150 kW to meet this load[3].

The four scenarios in Table.1 are compared for the best economic and environmental performance. The first scenario considers the 128 kW DG set meeting the 95 kW load; scenarios two and three consider the 150 kW Li-ion BESS charged by the grid at commercial and industrial tariff respectively, to meet the same critical load. Similarly, scenario four considers the 150 kW Li-ion BESS charged from a solar PV system which is owned by a developer or third party. Thus, the C&I consumers are only subject to the levelized cost of solar generation in scenario four.

For the comparative analysis, capital cost values, technical and operational parameters were collected from local suppliers and through online research. The financial input parameters are based on a recent general tariff order for grid interactive PV solar energy generating systems by the Tamil Nadu Electricity Regulatory Commission (TNERC, 2021). The calculations assume the same loan parameters for the DG set and BESS. These input parameters are presented in the Annexure of this document.

To account for the differences in upfront costs and its implications on the levelized cost, minimum, maximum, and average capital cost values were defined as input variables for the LCOE and LCOS calculations. A comparative analysis is also carried out for 1 to 10 hours of operation or back-up per day (hereafter referred to as hours of autonomy). To gain additional insights into the relative effects of capital expenditure (CAPEX) and operational expenditure (OPEX), the fixed and variable components of the LCOE and LCOS are presented.

The environmental and human health impacts of the DG set and BESS were compared using the relative greenhouse gas emissions and air pollutants that can cause damage to health. They are evaluated in terms of – grams of gas emissions for every kWh of electricity from the DG set and BESS. The greenhouse gas emissions were weighted in terms of their global warming potential – that is the carbon dioxide equivalent (CO_2e).

[2] Present value (PV) is the current value of a future sum of money or stream of cash flow given a specified rate of return.
[3] The size of the BESS is higher due to other kinds of losses accounted for with the depth of discharge (DOD) and round trip efficiency.

03 COMPARISON

The economic implications of meeting a critical load (95 kW) were compared under four scenarios – i.e, with a DG set, and a BESS charged at three electricity tariffs. As the nature of the technologies are different, the DG set and BESS are expected to have different CAPEX and OPEX contributions towards their respective levelized costs. The following analysis explores the impact of variable CAPEX, hours of autonomy, fuel price on the LCOE and LCOS, in order to discover the most economic back-up scenario for C&I consumers in Tamil Nadu.

CAPITAL COSTS

Capital costs obtained from suppliers[4] and online sources allowed us to define a minimum, average and maximum cost for the BESS and the DG set. The obtained cost ranges (refer to Table 2) show that the difference in the minimum, average and maximum cost of the DG sets (in INR per kW) are relatively small compared to the range of the battery pack costs (in INR per kWh)[5]. Also Li-ion BESSs have a much higher upfront costs, especially for longer hours of autonomy as compared to a DG set.

Table 2: Range of capital costs for DG sets and Li-ion battery packs assumed for the analysis. analysis.

No		DG set Cost (INR/kW)	Li-ion Battery pack Cost (INR/kWh)
1	Minimum	5,313	16,067
2	Average	6,648	22,172
3	Maximum	8,281	28,309

LEVELIZED COST OF ENERGY AND STORAGE

The levelized cost analysis was carried out for the four scenarios described in Table.1. The scenarios related to BESS have three different charging costs (based on the source of electricity and consumer type). These include: (1) INR 6.67/kWh for the HT I-A industrial tariff (TANGEDCO, 2017), (2) INR 8.4/kWh for the HT-III commercial tariff (TANGEDCO, 2017)[6], and (3) INR 3.95/kWh (solar tariff inclusive of network charges)[7].

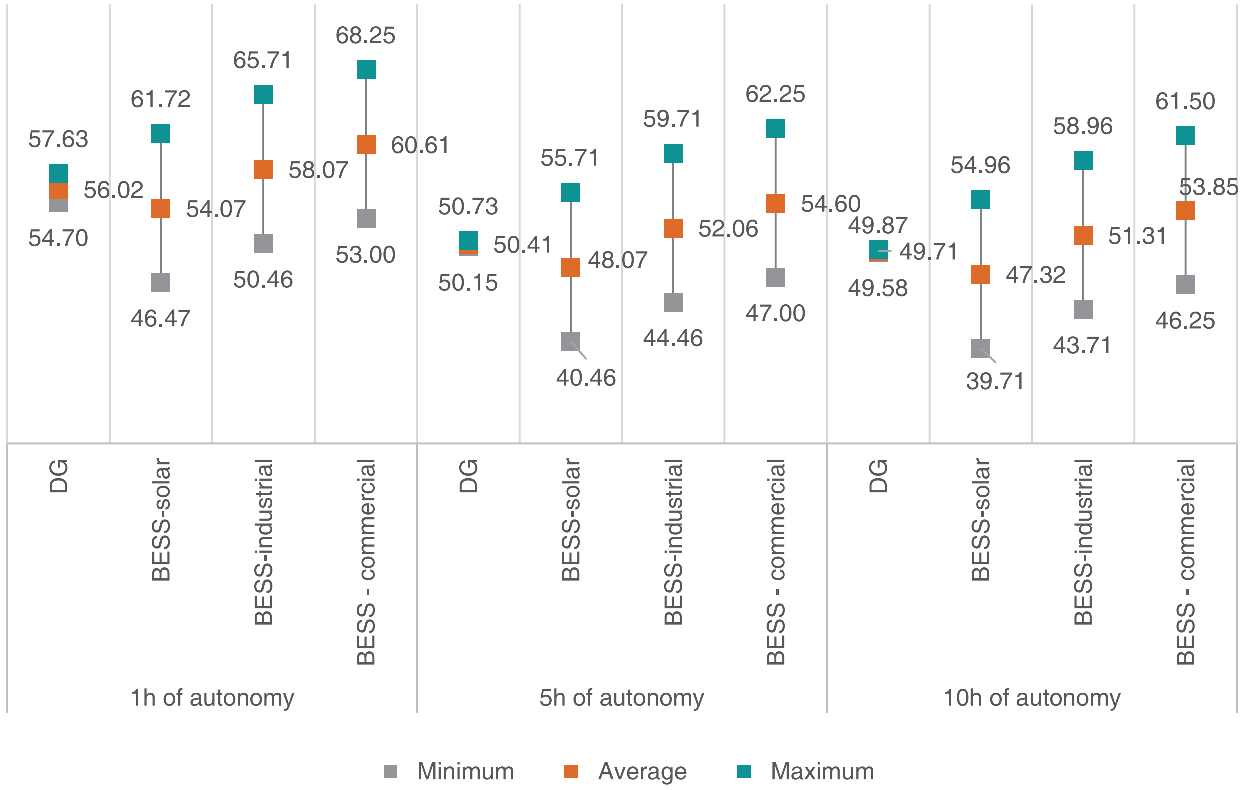
[4] Suppliers of each technology quoted different capital costs for DG sets and BESS. Additionally, BESS suppliers quoted different per kWh battery pack costs for different hours of autonomy. However, for this study the cost was assumed constant for all hours of autonomy in the LCOS calculations. Only the variation in price due to supplier was considered (refer to values in Table. 2).
[5] Based on the supplier quotes the battery pack cost makes up almost 70% of the total system cost.
[6] The commercial and industrial tariffs quoted are inclusive of 5% electricity tax (Tamil Nadu Energy Department, 2003).
[7] The solar tariff, which is the levelized cost of electricity from rooftop solar systems of 501-999 kW, i.e 3.12 INR per kWh, includes the addition of network charges for HT consumers, i.e 0.83 INR per kWh as per (TNERC, 2021).

The levelized cost analysis, shows that the LCOE of DG set[8] varies in a narrow range compared to the variation of LCOS for BESS (refer to Figure 1). This is on account of a lower CAPEX variation of the DG set as compared to BESS. As the hours of autonomy or back-up time required increases, the difference in CAPEX has less significance on the LCOE of the DG sets. However, the variation remains significant for the BESS under all the scenarios.

The LCOE and LCOS are the highest for 1 hour of autonomy, and they decrease as the back-up hours required increase. Thus, depending on the CAPEX and hours of autonomy, the LCOE of the DG set varies between INR 49.58-57.63/kWh and the BESS's LCOS varies between INR 39.71-68.25/kWh, (refer to Figure 1).

The results also indicate that the BESS becomes more economical than the DG set, under all three tariff-based scenarios, only when the minimum battery pack costs are considered. As the battery pack costs increase, only at lower charging tariffs does BESS become competitive with DG. With the average capital costs, BESSs can compete with DG sets only if charged at the solar tariff. Thus, the battery pack costs play a significant role in determining the competitiveness of the technology.

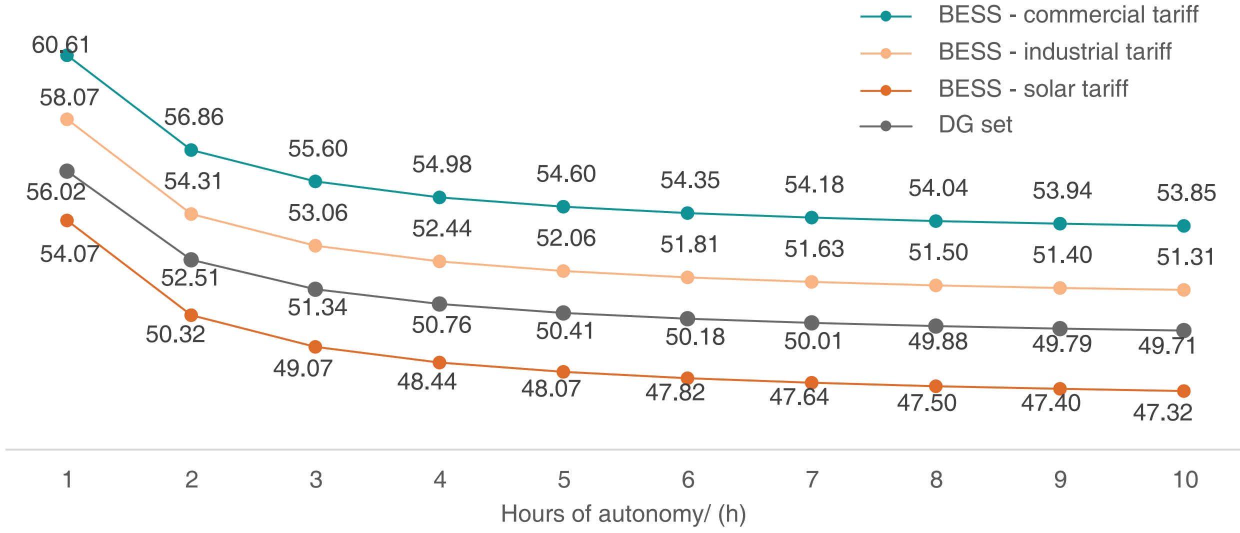
Figure 1: DG set LCOE and BESS LCOS comparison (in INR per kWh) based on CAPEX range (minimum, average, and maximum), different tariff rates (solar, industrial and commercial), and hours of autonomy.



Comparing for the average capex range for both BESS and DG set, BESS only provides a more attractive per unit cost over the DG set in the case that the system is charged from solar, and this so for all ranges of autonomy (refer to Figure 2).

[8] *The DG LCOE is inclusive of an applicable electricity tax of INR 0.1 per unit generated (Tamil Nadu Energy Department, 2003).*

Figure 2: Variation of LCOE and LCOS (in INR per kWh) over 1-10 hours of autonomy for DG and BESS[9] (without subsidy).

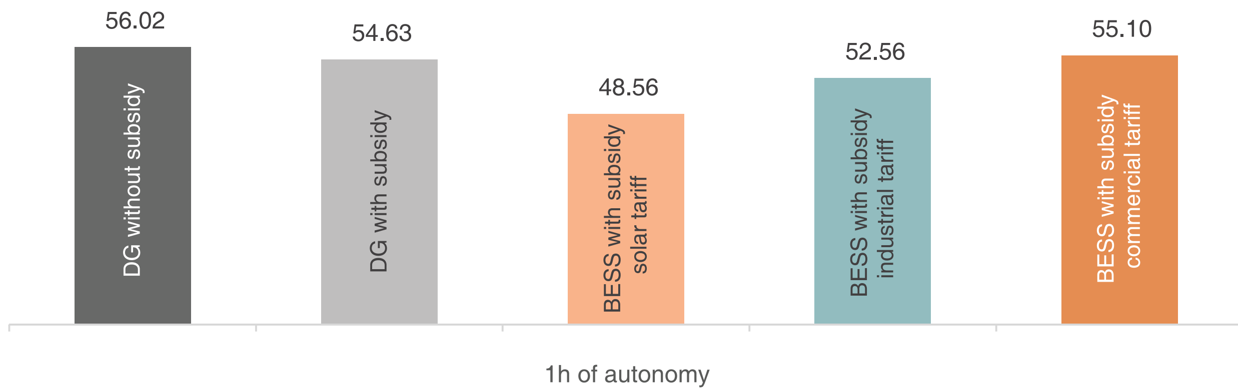


Subsidies are one way of reducing capital costs of systems. However, currently, a subsidy scheme exists only for DG sets. The generator subsidy scheme in Tamil Nadu offers 25% of the capital cost (with a cap of 5.00 lakhs), for manufacturing MSMEs and for DG sets of up to 320 kVA (~256 kW) (MSME Department Tamil Nadu, 2017). The results in Figures 1 and 2 do not include any capital subsidies. Even with the available capital subsidy for DG sets the LCOE of DG set would remain higher as compared to the LCOS of a BESS charged from solar.

If the same capital subsidy allocation were made for DG sets and for BESS, the LCOS of BESS charged from solar and at an industrial tariff rate is lower than the per unit cost of DG sets. Even the LCOS of BESS charged with a commercial tariff rate becomes competitive with a DG set. And if subsidy for DG sets were to be phased out and re-directed to BESS, then the LCOS of BESS will be more attractive in all three scenarios (refer to Figure 3).

The same analysis conducted with maximum capital costs indicated that when subsidy was applied to both types of systems, BESS had a lower levelized cost only when charged at the solar tariff. However, the subsidy reduces the LCOS by a significant INR 6.66/kWh.

Figure 3 LCOE and LCOS (in INR per kWh) with subsidy for 1 hour of autonomy[10].



[9] *The values calculated in Fig.2 assume average capital costs of the DG set and BESS.*
[10] *The values calculated in Fig.3 assume average capital costs of the DG set and BESS.*

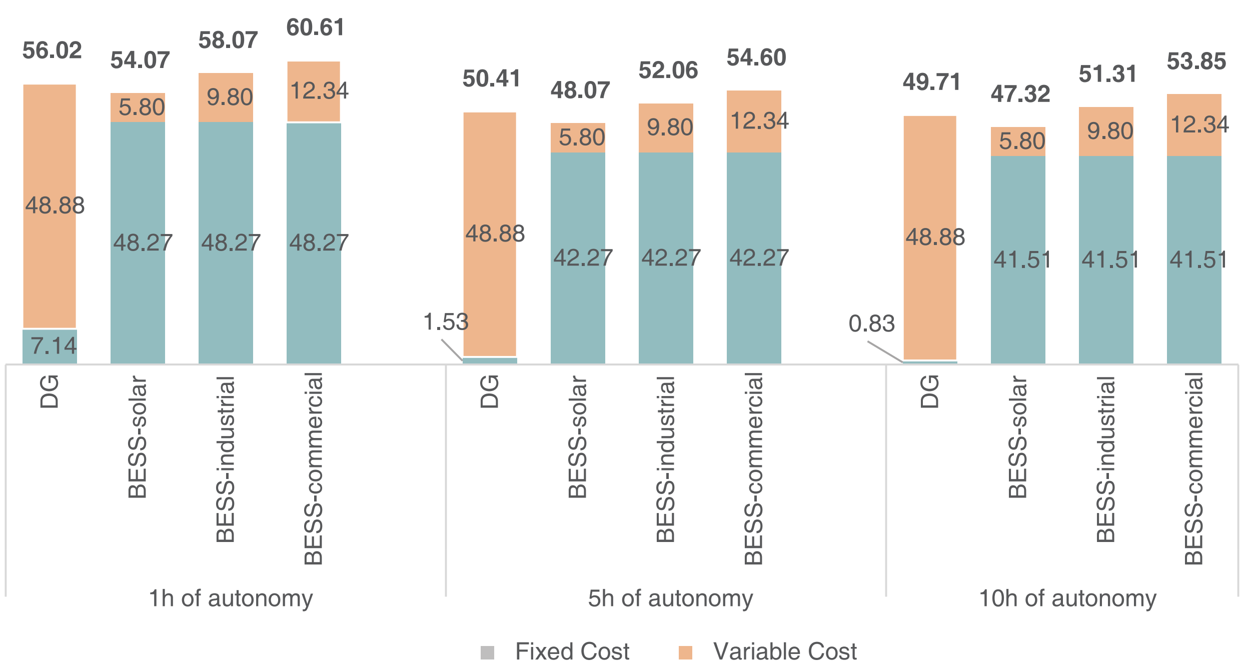
Redirecting the same capital subsidy to BESSs could significantly improve their competitiveness against DG sets. However, the most economical option for C&I consumers, is consistently when the BESS is charged from solar, with or without subsidy.

FIXED AND VARIABLE COSTS

The LCOE and LCOS can be broken up into two cost components, these are the fixed cost and the variable cost (refer to Figure 4). The fixed cost component reflects the proportion of the asset cost that makes up the LCOE and LCOS, as opposed to the operational costs. The latter is reflected in the variable component of the cost. It accounts for the costs that recur over the back-up system's lifetime, such as the O&M costs and fuel costs.

For the DG set the variable cost component is the single largest determining factor for the LCOE, whereas for the BESS, the fixed cost component makes up the majority of the LCOS (refer to Figure 4). In general, the fixed cost component reduces with hours of operation, as when the hours of autonomy increase, more units of electricity are supplied for the same upfront investment, resulting in a better asset utilization. On the other hand, the variable component depends primarily on factors related to fuel prices or electricity prices.

Figure 4: Fixed and variable cost components of the LCOE and LCOS (in INR per kWh) for different hours of autonomy and electricity tariffs[11].



The results in Figure 4 indicate that the factor that influences the LCOS most is the CAPEX of the system, whereas the LCOE of the DG set is dominated by the cost of diesel.

SENSITIVITY ANALYSIS WITH FUEL PRICE

The cost of fuel influences the levelized costs of both the back-up systems. The sensitivity analysis of the LCOE and LCOS with diesel price and electricity respectively, indicate that the fuel costs can also dictate which back-up system is more economical (refer to Figure 5 & Figure 6). For example, if the diesel price is reduced to INR 80/l, the DG set may prove more economical than a BESS charged at the current industrial and commercial grid tariffs (refer to Figure 5 & Figure 6). However, if the diesel price increases or remains at the assumed price (INR 90/l), the BESS may prove financially more beneficial.

[11] The values calculated in Fig.4 assume the average capital costs of the DG and BESS.

Figure 5: Sensitivity analysis of the LCOE with diesel price for different hours of autonomy[12].

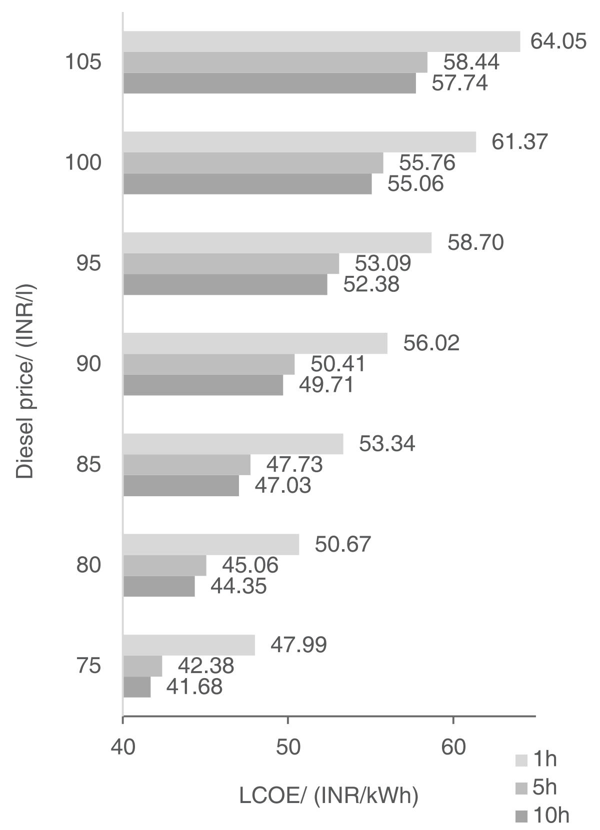
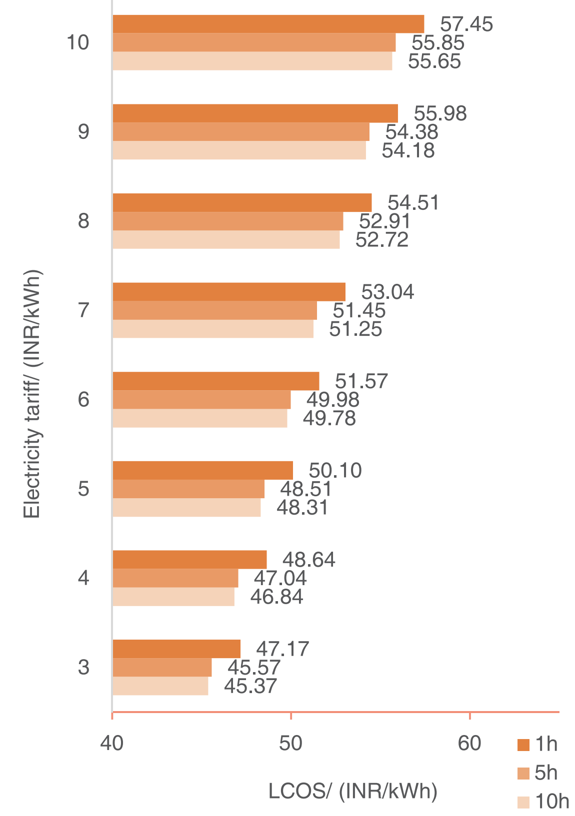


Figure 6: Sensitivity analysis of BESS with electricity tariff for different hours of autonomy[13].



It can be noted that the electricity tariff has a larger impact for the lower hours of autonomy. The LCOE and LCOS change minimally after five hours of autonomy.

In conclusion, the competitiveness of Li-ion BESS is vulnerable to a decrease in diesel price and hike in the battery pack costs. On the other hand, the levelized cost of the DG set, is vulnerable to an increase in fuel cost, which is a possible future scenario.

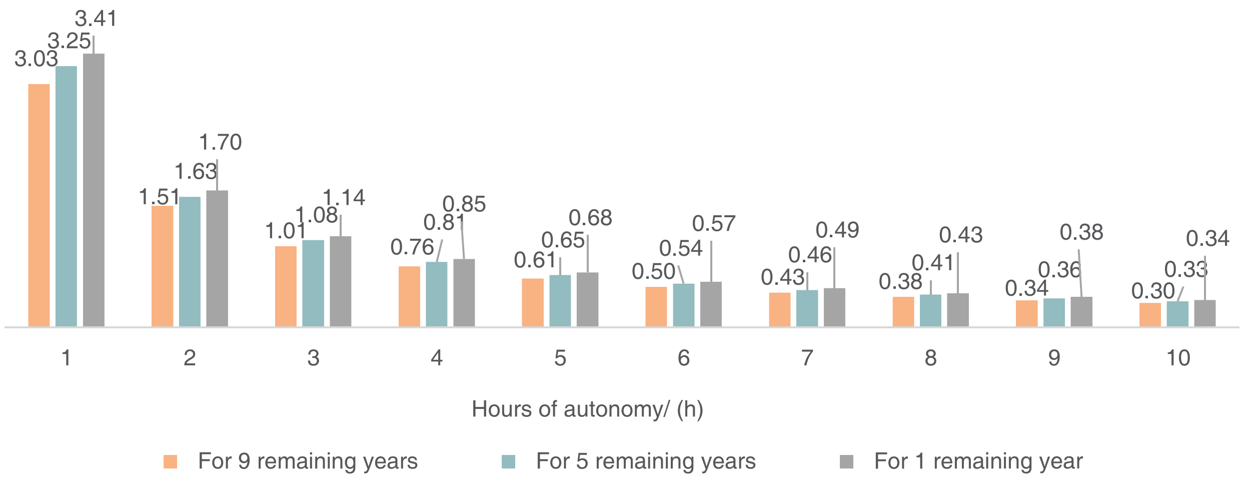
RETROFITTING THE DG SET

As per the Indian Government's new regulations, older DG sets are mandated to limit their emission within the Central Pollution Control Board (CPCB) norms. DG set operators are directed to control the emissions by installing a Retro-fit Emission Control Device (RECD) on the DG set (CPCB, 2019). This requires an additional CAPEX, which in turn increases the LCOE.

An analysis was done to assess this increase in LCOE due to the additional installation of an RECD for 128 kW DG sets with different life-years remaining (from 9 years to 1 year). It was found that LCOE will increase by INR 0.30-3.41/kWh based on the remaining plant life years and the hours of autonomy (refer to Figure 7). With retrofitting equipment, DG set's LCOEs become significantly costlier for lower hours of autonomy.

[12] The values calculated in Fig.5 assume the average capital costs of the DG and BESS without any subsidy.
[13] The values calculated in Fig.6 assume the average capital costs of the DG and BESS without any subsidy.

Figure 7: Additional cost (in INR per kWh) to LCOE on account of retrofitting the DG set



COMPARISON OF EMISSIONS

DG sets are an important contributor to air pollution levels. Combustion of diesel during the operation of DG set produces toxic air pollutants; this includes particulate matter combined with oxides of carbon, nitrogen, and sulfur. The most harmful pollutants from a DG set is fine particulate matter (PM2.5) which can be inhaled deep into the lungs causing diseases and premature deaths. All the above-mentioned emissions cause serious health threats to respiratory-sensitive individuals and act as a cause of disease burden to the overall population.

For the year 2019, the Institute for Health Metrics and Evaluation (IHME) estimated 1.67 million deaths in India due to PM 2.5 exposure. The disease burden is measured as Disability-Adjusted Life Years (DALY). One DALY is the numerical equivalent of one lost year of a healthy life. As per the study, India lost 53.50 million healthy life years in 2019 (India State-Level Disease Burden Initiative Air Pollution Collaborators, 2019). Table 6 shows the relative emissions per kWh of the selected power backup solutions. Only emissions related to the on-site generation of electricity or sourcing of electricity are considered; other emissions resulting from the extraction of resources required to build up installed capacity, emissions from transportation, mining of fuels, and end-of-life-related emissions are not accounted for in the analysis.

Table 6: Comparison of emissions[14].

No		Greenhouse gases emission rates (gram per kWh)	Rate of air emissions that impact human health (gram per kWh)		
		CO_2e	NO_x	SO_x	PM
1	DG sets	700.00[15]	5.16[16]	2.31[16]	0.20[17]
2	BESS charged from solar	0.00	0.00	0.00	0.00
3	BESS charged from grid	940.00[18]	2.30[19]	5.88[20]	0.33[21]

[14] The emissions do not factor in distribution and transmission losses.
[15] Based on grid emission factor of Diesel generators from CEA, 2021.
[16] Suthar, G. et al., 2018
[17] CPCB, 2021
[18] Based on grid emission factor from CEA, 2021 and round-trip efficiency of the BESS as 85 %.
[19] Based on grid emission factor from NTPC, 2021 and round-trip efficiency of the BESS as 85 %.
[20] Based on grid emission factor from CEA, 2021 and round-trip efficiency of the BESS as 85 %.
[21] Based on grid emission factor from CEA, 2021 and round-trip efficiency of the BESS as 85 %.

04 ENABLERS

FALLING PRICES OF BESS

The price of Li-ion technologies has reduced significantly in the past 3 decades due to technological improvements and wider application scope (Ritchie, 2021). Li-ion technologies have seen a drop in price of more than 89% from 2010 to 2020, with further reductions expected (Bowen, T. et al., 2021). This decline in prices and improvement in performance act as a driver for the future adoption of BESS.

RISING COST AND SUPPLY CHAIN INSECURITY OF DIESEL

The price of diesel depends on various factors, of which two major ones are international cost and demand for crude oil. India's diesel needs are met by imports from several other countries (Trading Economics, 2022) and the average price of diesel has observed an average escalation of 8% per year from 2017 to 2022 (PPAC, 2022). Given the geopolitical situation as of May 2022, it is very likely that diesel prices will further increase in the coming years. The possible risks around supply reliability and the higher cost of diesel propel consumers to look for alternative solutions such as BESS.

EMISSION NORMS FOR DG SETS

Tamil Nadu Pollution Control Board (TNPCB) has issued a notification to retrofit old DG sets used in C&I establishments with a capacity of 125 KVA and above (TNCP, 2021). Types of regulations like these to control air pollution – i.e.: imposing stringent emission and noise limits, enforcement of seasonal operational bans like winter bans imposed in Delhi and the NCR region and forcing customers for retrofitting- pose a risk in terms of additional investment, to future DG set buyers. It is quite likely that the government will mandate more stringent air pollution and noise pollution norms for DG set in the near future.

POWER QUALITY

BESS can be an attractive option or alternative for C&I entities that require a high-quality back-up power supply (NREL,2021). For example, it is necessary to ensure the quality of power delivered to data centres used in banking financial service and insurance companies, since the power quality issues may impact the IT equipment or network services (Delta Power Solution, 2016), (Neudorfer, 2020).

• CASE STUDY 1

Power quality – Avoiding financial losses due to power quality with BESS in Czech Republic

One of the Škoda car manufacturing units in the Czech Republic faced interruptions during the manufacturing and production process due to frequent voltage dips. As a result, the company faced significant financial losses. To avoid experiencing these voltage dips and any grid failures, a BESS that ensured an uninterrupted power supply was installed on site. The system automatically detects and acts on the voltage and outage problems, and supports the required load (FREQCON, 2019).

ENABLERS

Falling prices of BESS

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• CASE STUDY 2

Market Design - Bring your device Program-Vermont, United States of America

Green Mountain Power, a distribution company based in Vermont has implemented an innovative incentive program for BtM-based BESS. Under this program, residential and small business customers can receive incentives for the battery storage if they let this distribution company to draw power from the battery at times. The incentives include USD 850 per kW enrolled for three-hour discharge and USD 950 per kW for four-hour discharge. Peaks occur 5 to 8 times a month with an average duration of 3 to 8 hours (Green Mountain Power, 2022). The fleet of battery storage systems under this program acts as a virtual power plant and is used to manage peak power demand. In this way, the consumer benefits from the system as a back-up and also financially, while the distribution company benefits from its grid balancing services.

BARRIERS

Lack of awareness and perception of higher prices

C&I entities lack awareness about the currently available BESS technologies and their economic viability. This lack of awareness could be partly explained by the lack of proper media outreach and outdated notions about the price of BESS (Motyka et. al, 2022). Both the above factors give a limited perception of BESS, which cumulatively acts as a barrier to its adoption.

Financing barriers

There is a lack of financing or funding schemes for BESS deployment. BESS is known to have a high upfront cost and a wide range of applications. Financial support, such as low-interest loans, subsidies, or tax credits may be designed differently for different consumer categories based on their energy and economic requirements.

Lack of market design

Currently there is also no market for a variety of grid services that a 'grid-active' BESS can provide. If such a marketplace was existing, the BESS backup system can generate additional income by providing services to the grid operators.

05 WAY FORWARD

Long term planning to meet climate commitments

During the 26th Conference of Parties (CoP 26) India announced that it will target net-zero emissions by the year 2070. In order to meet this target, India will increase the capacity of non-fossil-based power generation to 500 GW by the year 2030 (MEA, 2021). To facilitate the higher integration of variable renewable energy sources, grid flexibility services will be essential. BESS can provide these services and therefore become an essential component of decarbonizing the electricity grid and meeting the country's climate commitments.

Market design

BESS can provide a suite of grid services and applications including: energy arbitrage, frequency regulation, spin non-spin reserves, voltage support, black start, resource adequacy, distribution deferral, transmission congestion relief, transmission deferral, time of use bill management, increased solar PV self-consumption, demand charge reduction, and backup storage (RMI, 2015). Forward-looking regulations will be required to leverage such grid services by BtM BESS.

Recycling and repurposing

The increased use of BESS is leading to concerns from policymakers and stakeholders about its environmental consequences. This underlines the need for end-of-life collection and recycling of batteries. It is also a solution to address India's limited deposits of key minerals and metals for battery manufacturing. BESS made with repurposed EV batteries could also be a good way to address the scarcity issue. These measures will reduce the overall carbon footprint of the supply chain since recycled minerals is having a lower carbon process than mining. In short, recycling policies based on circular economy principles need to be developed foreseeing long-term BESS deployment targets.

Redirecting capital subsidies from DG sets to BESS

There is a lack of financing or funding schemes for BESS. On the other hand, the subsidies, and loans available for DG sets make them financially more competitive. These subsidy schemes are available for micro, small and medium manufacturing enterprises, for DG set of up to 320 kVA capacity. It entails a reduction of 25% of the capital cost (with a cap of 5 Lakhs) (Government of Tamil Nadu, 2017). Considering multiple health, environmental, and grid integration benefits of BESS implementation, the subsidies allocated for DG sets should be reviewed so that they could be redirected to support the upfront cost of BESS adoption. The same subsidy extended also to BESSs lowers their LCOS, to match or even drop below the DG sets' LCOE.

• CASE STUDY 3

Market Design – Benefitting from the Time-of-Day tariff with Energy Storage in Mexico

An energy storage as a service based business model is being rolled out through a partnership by Future Renewable Ventures, US- Energy Toolbase, and a local developer Ecopulse. The C&I customers adopting this energy storage service model will not have to undertake an upfront capital investment, instead, the customers will share their electricity cost savings with the project partners. Savings will be earned by adopting a discharge strategy based on time of the day tariff and demand charges (Colthorpe, 2022), (FRV, 2022).

SUMMARY AND RECOMMENDATIONS

The LCOS of the Li-ion based BESS charged with solar was found financially most attractive across all simulated autonomy ranges. This technology proposition also provides the cleanest form of backup power since no emissions are generated during power generation.

Key recommendation for the Government of Tamil Nadu are:

1. Accelerate the implementation of emission norms for DG sets.
2. Halt the current capital subsidy for DG generators for MSMEs and re-direct the subsidy to incentivise MSMEs to adopt BESS as power back-up solutions.
3. Design appropriate market mechanisms and feed-in tariffs to encourage the deployment of grid-active storage systems.
4. Launch an awareness and training building program and build technical capacity among C&I entities.
5. Implement pilot projects in industrial parks managed by State Government entities.

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APPENDIX

ANNEXURE-I GENERAL ASSUMPTIONS

No	Parameter	Value	References
1	Critical load (kW)	95.00	Assumption
2	Annual days of operation (Day)	365.00	Assumption
3	Discount rate	8.67%	TNERC 2021
4	Equity	30.00%	TIIC 2019
5	Return on equity	15.60%	TNERC 2021
6	Loan tenure (year)	7.00	TIIC 2019
7	Moratorium (year)	0.50	TIIC 2019
8	Interest on loan	11.95%	India Filings 2022
9	Insurance (% of depreciated asset value	Assumed as part of O&M cost	TNERC 2021
10	Working capital O&M (month)	1.00	TNERC 2021
11	Working capital – receivables (month)	2.00	TNERC 2021
12	Working capital - maintenance spares (%)	15.00%	TNERC 2021
13	Interest on Working capital	10%	TNERC 2021
14	Depreciation rate	15.00%	Income Tax Department Government of India 2021

ANNEXURE-II

Assumed capital cost data for 128 kW DG sets

No	Parameter	Minimum	Maximum	Average	Reference
1	Capital cost(INR per kW)	5,313.00	8,281.00	6,648.00	online research and quotes received from suppliers
2	Installation and commissioning costs (INR per kW)	-	-	468.75	Online research and quotes received from suppliers
3	Soft costs-taxes (%)	-	-	18%	Online research and quotes received from suppliers
4	Subsidy	-	-	25% of capital cost with a cap of 5.00 lakhs.	Government of Tamil Nadu 2017

ANNEXURE-III

Parameters for emission analysis-DG systems

No	Parameter	Average	Reference
1	Price of the retrofitting equipment (Lakhs)	3.50	Online research and quotes received from suppliers

ANNEXURE-IV

Assumptions on general operational and financial parameters for the LCOE analysis-DG sets

No	Parameter	Average	Reference
1	Plant capacity (kW)	128.00	Online research and quotes received from suppliers
2	Power factor	0.80 (lag)	Online research and quotes received from suppliers
3	Load factor (%)	75%	Assumption
4	Working capital-fuel (months)	4	Income Tax Department Government of India 2021
5	Specific fuel consumption (litres per hour)	28.07	Online research and quotes received from suppliers
6	Fuel cost (INR/litres)	90.00	Ministry of Petroleum and Natural Gas 2022
7	Fuel escalation rate (%)	8.00%	Ministry of Petroleum and Natural Gas 2022
8	Capacity degradation rate (%)	2%	Generator Source (2022).
9	Operation and maintenance expenses for Year 1 (INR per hour)	44.69	Online research and quotes received from suppliers
10	The annual increase in O&M expenses (%)	5.00%	Online research and quotes received from suppliers
11	The Tamil Nadu Tax on Consumption or Sale of Electricity for generating plant (INR/kWh)	0.1	Tamil Nadu Energy Department 2003

ANNEXURE-V

Assumed Capital cost data for BESS systems

No	Parameter	Minimum	Maximum	Average	Reference
1	Capital cost-battery pack (INR per kWh)	16,067.10	28,308.70	22,171.70	Online research and quotes received from suppliers
2	Capital cost-grid passive Inverter (INR per kW)	-	-	8,000.00	Online research and quotes received from suppliers
3	Balance of System costs-(INR per kWh)	-		7,240.27	Online research and quotes received from suppliers
4	Installation and commissioning costs (INR per kWh)	-	-	2,261.00	Online research and quotes received from suppliers
5	Soft costs-taxes (%)	-	-	18%	Online research and quotes received from suppliers

ANNEXURE-VI

Assumptions on general operational and financial parameters for the LCOS analysis-BESS

No	Parameter	Average	Reference
1	Round trip efficiency (%)	85%	Online research and quotes received
2	Depth of Discharge (DoD)	89%	Online research and quotes received
3	Cycle life at given DoD (cycle	3,167.00	Online research and quotes received
4	Storage shelf life (year)	13.00	Online research and quotes received
5	End of life capacity relative to the initial capacity	80%	Online research and quotes received
6	Cost of the electricity from grid for commercial consumers in TN(INR per kWh) with 5% tax	8.40	TNERC 2021
7	Cost of the electricity from grid for industrial consumers in TN (INR per kWh) with 5% tax	6.67	TNERC 2021
8	Cost of electricity-from Solar PV with network charges in TN (INR per kWh)	3.95	TNERC 2021
9	Tariff escalation	4%	Unni et al., 2021
10	Daily battery cycling (cycles)	1.00	Assumption
11	Operating cost (year 1) – Energy (INR/kWh-yr)	215.00	Online research and quotes received
12	Inverter efficiency (%)	96%	Unni et al., 2021
13	Inverter replacement year (years)	14.00	Unni et al., 2021
14	The annual increase in O&M expenses (%)	6.95%	Online research and quotes received
15	Insurance (% of depreciated asset value)	Assumed part of O&M cost	TNERC 2021

ANNEXURE-VII

Parameters for emission analysis-DG sets

No	Parameter	Average	
1	NOx emissions (g per kWh)	5.16	Suthar, G. et al. 2018
2	SOx emissions (g per kWh)	2.31	Suthar, G. et al. 2018
3	PM emissions (g per kWh)	0.20	CPCB, 2021
4	CO2e emissions (g per kWh)	700.00	CEA 2021

ANNEXURE-VIII

Parameters for emission analysis-BESS

No	Parameter	Average	Reference
1	Grid NOx emissions per kWh (g per kWh)	1.93	NTPC 2021
2	Grid SOx emissions (g per kWh)	4.94	NTPC 2021
3	PM emissions (g per kWh)	0.28	NTPC 2021
4	CO2e emissions (g per kWh)	790.00	CEA 2021