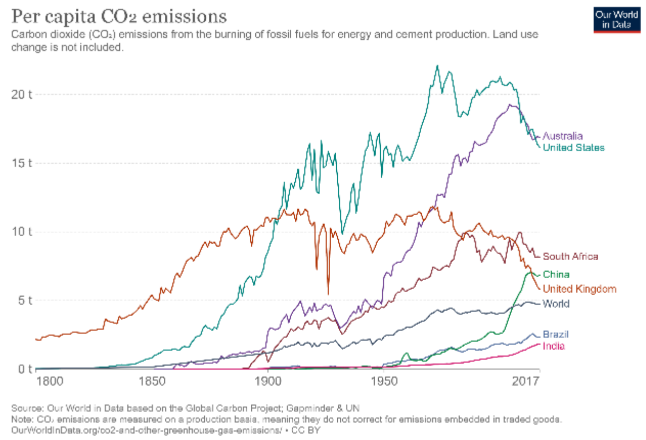
India’s Renewable Energy Tangle

Ashok Jhunjhunwala, Kaushal Kumar Jha and Anson Sando

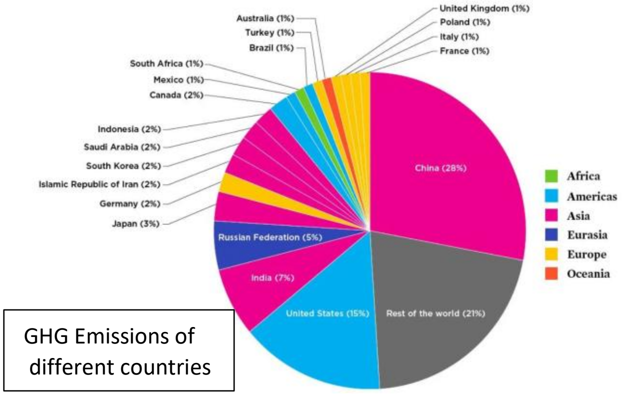
With the threat of Global warming rising every year, immediate actions are called for from every part of the world. India is 103rd in terms of per-capita CO2 emissions[1] and can argue that the onus of reversing global-warming is on the developed world, which consumes significantly more. India is in its development stage and needs to grow and consume more.

However, India ranks 3rd in the world[2] in terms of Green-House Gas (GHG) emissions, resulting from being 3rd largest[3] in energy consumption. Also, with rapidly growing GDP, resulting into higher incomes, India’s energy consumption is likely to grow rapidly and so will its GHG emissions. It has already seen a staggering increase by 335% since 1990. Use of air-conditioning is growing exponentially in India and while 8% of its homes use it today, it is likely to become 50% by 2050[4].


Per capita CO₂ emissions

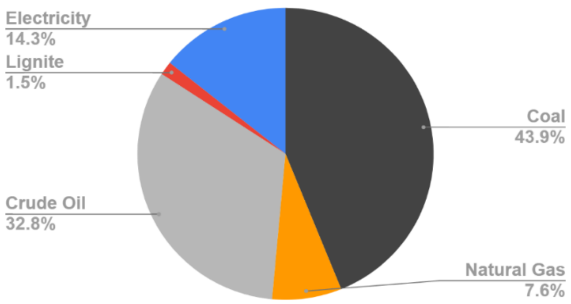
Carbon dioxide (CO₂) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.

Source: Our World in Data based on the Global Carbon Project; Gapminder & UN
Note: CO₂ emissions are measured on a production basis, meaning they do not correct for emissions embedded in traded goods.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY



GHG Emissions of different countries

Consumption of Energy Sources in India (2020)



Consumption of Energy Sources in India (2020) [ref}

India’s energy usage is dominated by fossil fuels. Its electricity comes primarily from coal for industrial and domestic consumption. Industrial heating requirement is met mostly by coal-based electricity as well as burning of coal and gas directly in furnaces. Domestic and

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[1] EDGAR EU 2020 Report, https://edgar.jrc.ec.europa.eu/report_2020

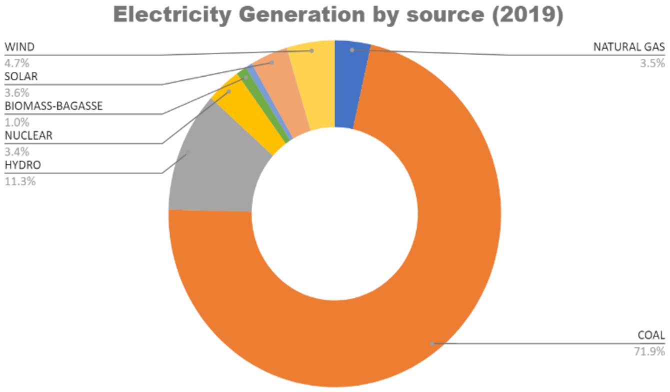
[2] Hannah Ritchie and Max Roser (2020) - "CO₂ and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions' [Online Resource]

[3] IEA (2020), Key World Energy Statistics 2020, IEA, Paris https://www.iea.org/reports/key-world-energy-statistics-2020

[4] Ritika Jain (2020), Cooling India with Energy Efficient Solutions, The Energy and Resources Institute

Industrial cooking is largely LPG based supplemented by coal / biomass and transport primarily uses petrol and diesel.

Renewable Energy (RE) generation in India today costs lower than fossil-fuel based electricity. The cost of solar energy in India has gone down to 2.7₵ per kWh[5], whereas it is 3.4₵ for wind-based electricity. On the other hand, electricity from coal costs between 2.7₵ per kWh (from old plants) and 5.5₵ from newer plants with additional pollution control equipment. Cost of electricity generated from gas and petrol is many times higher. The steady decline in the price of RE has resulted in a substantial increase in the installed capacity of RE to 100 GW, amounting to 25% of electricity, whereas coal capacity is 53%. Further, the Government of India has fixed a target of 450 GW by 2030[6]. Yet in terms of energy generated in 2019, about 72% of electricity was produced from coal and only 8.3% from RE. This is because the capacity utilisation for RE varies from 20% to 30% whereas it can touch 90% for coal. Solar and wind-based electricity is available only during certain hours of the day and certain months of the year. As RE capacity grows, the only way to reduce coal in the electricity mix is by adding energy storage for RE. Some of the newer RE plants are being set up with associated large storage. However, there is another way to move faster.



https://powermin.nic.in/en/content/power-sector-glance-all-india

India has some 40,000 commercial complexes, consisting of offices, research centers as well as shopping centers and restaurants, consuming over 8% of the total electrcity. The number of such complexes are likely to triple over the next 10 years[7] and they get electricity from utilities at rates higher than that for industrial and residenential sectors. The complexes are brand-concious and would like to project themselves as user of only Renewable Energy. Similarly industrial complexes consume about 40% of electrcity in the country today, and most of them would be happy to move towards 100% RE. Many of these complexes are already using roof-top solar but limited roof-top space limits it to 10% to 15% of their energy usage. These complexes can however leverage a unique power-transmission and wheeling policy that is available in India, wherein an independent power-generation company can set-up solar and wind-power generation for multiple consumers in a *group-captive* model, in which each consumer invests in the desired amount of RE capacity. The RE generated for a

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[5] Here we have used \$1 = ₹73 where ₹ is the Indian currency.

[6] Ministry of New and Renewable Energy, 2020 https://pib.gov.in/PressReleseDetailm.aspx?PRID=1662145

[7] India's commercial building footprint alone is projected to triple to ~1.7 billion m2 (19 billion sqft) by 2030. In conjunction, projections also indicate that Indian building energy use will triple by 2030, fueled by explosive growth in building footprint and rising living standards that lead to higher levels of building services per capita (e.g., lighting, plug loads, cooling).

customer can then be wheeled-in[8] to its complex using the existing power transmission and distribution network of utilities at a cost as per the Open Access policy[9] of Government of India. If the complexes add RE-storage and store any excess RE as and when produced and then use it as and when needed, it is possible for them to move closer to being a 100% RE user. If enough commercial, industrial and residential complexes adopt this approach, India could move away from coal-based electrcity rapidly.

IITM Research Park (IITMRP) at Chennai is a 1.2 million square feet complex housing R&D for over hundred companies and about 150 start-ups. The number of people working at IITMRP would be about 5000, when it is fully occupied and it would consume on average 40 MWh of electrcity per day during weekdays. It is now in the process of setting up captive 2 MW solar and 2.1 MW wind plants and wheel in the electricity so as to enhance its RE usage from the 10% today, coming from its rooftop solar plant, to 90% in about three years. More RE may be added later as required. IITMRP is also building two kinds of storage in its complex. The first being a Li Ion battery storage, and the second is a chilled water storage. The interesting thing is that by doing this it will reduce its power-costs in the process and this could act as a role model for other complexes to follow.

IITM Research Park

Technology and Economics of Energy Storage in India

As the cost of Li Ion cells tumble, batteries are emerging as one of the best and most-effective options for large energy storage. RE wheeled-in to the complex may be stored in such batteries and used when needed. The batteries have large up-front capital costs and have a limited lifetime in terms of the number of charge-discharge cycles. This lifetime depends on multiple other factors including charge-discharge rate (C-rate), temperature, depth of discharge (DoD), pack design and chemistry used. The cost of storage will add to the cost of RE depending on the interest paid on capital costs and the number of times the batteries will be charged and discharged per day.

We take batteries made out of three types of cells, that are commercially available today. Cell A is low-cost NMC, whereas Cell B is higher-end NMC with Si in graphite anode, and cell C is

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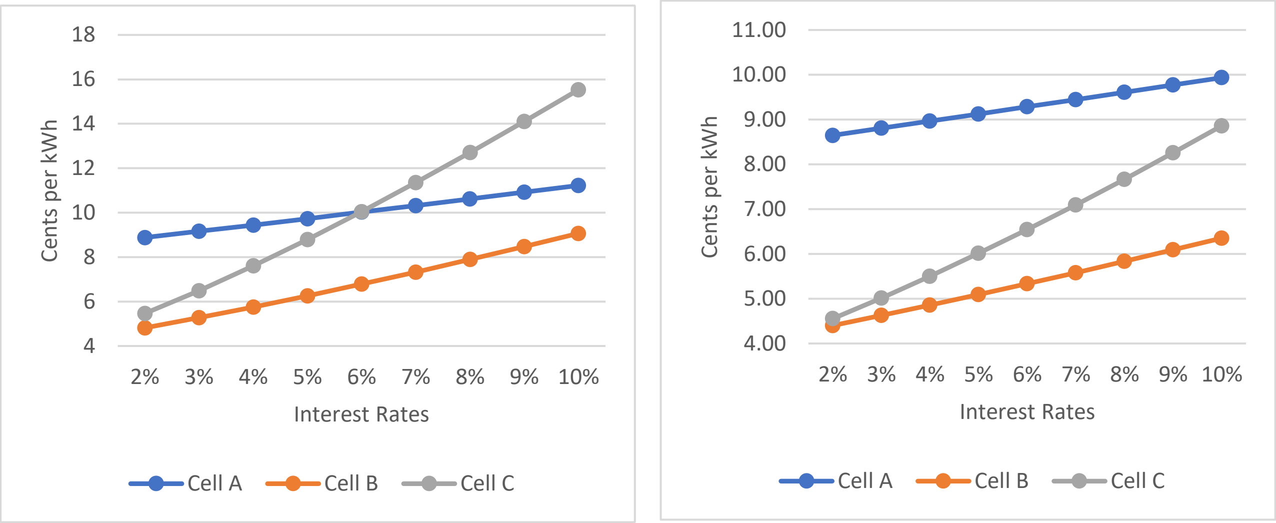
[8] Wheeling implies that the RE generating stations inject a certain amount of electricity on the grid and the same is delivered immediately to the consumer.

[9] Brookings India (2017), *Newer Challenges for Open Access in Electricity* https://www.brookings.edu/wp-content/uploads/2017/04/open-access_ds_042017.pdf

LTO. The cell-costs per kWh are for batteries of size greater than 1 MWh, and the number of equivalent full charge discharge cycles for the life of the battery are given in the table below:

	Cell A	Cell B	Cell C
Battery Costs ($/kWh)	150	250	500
Number of Cycles	2000	7000	15000



Depreciation and Interest Cost of Storage (left figure: 1 cycle per day, right figure: 2 cycles per day)

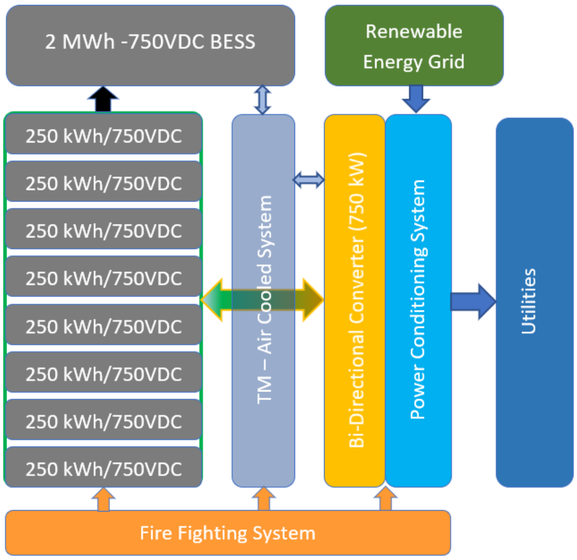
The batteries use 95% DoD and the charging-discharging has an end to end efficiency of 95%. The temperature is maintained at 25 °C and the rate of charging-discharging rates are lower than 0.5C. The per kWh cost of usage of a battery involving a single charge and discharge cycle is computed using the depreciation and interest costs per year, and the number of charge-discharge cycles used per year. The results are plotted in the figure as a function of interest rates for three cells for single charge-discharge and for 2 charge-discharge cycles used per day.

The results show that the cost of usage of the battery is highly dependent on the interest rates. For example, if interest rate is taken as 2%, as is prevalent in Europe and United States, the cost of usage is in between 4₵ to 5₵ per kWh of usage. But at interest rates of 10%, as is prevalent in countries like India, the costs go up to 9₵ per kWh for a single charge-discharge cycle a day, and falls to 6.35₵ per kWh, when 2 cycles are used per day. In both cases, the battery using cell B turns out to be the lowest costs. If the interest rates were 2%, one could have used LTO cells too.

Building Li Ion Storage

As the Storage part adds considerable costs to RE there is a strong need to minimise the capital costs of building the storage systems. The full storage system comprises of much more than the cells. Cost-optimisation is required in the design of battery packs and its interconnection to the grid.

Li-Ion battery storage systems consists of battery, layers of protection, bi-directional converters and a power conditioning system connected with grid and utilities as shown in the figure. A 2 MWh, 750VDC Li-ion storage system is designed with a C/3 rate of charge-discharge, limiting the current to 100A. Careful electrical and mechanical design is carried out to maximise battery-life. The Thermal management system maintains the cells close to 25°C to further increase cycle life. Finally, an Energy Management System acts as a bridge between all the systems including the Li-ion battery storage, bi-directional converter, grid and utilities to ensure optimal storage and consumption of renewable energy. A fire-fighting system is also integrated within the system to take over in case of any safety concerns.

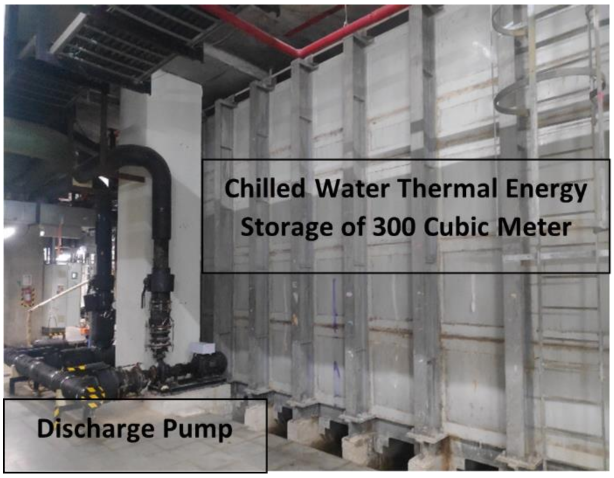


Thermal storage

In tropical countries like India with a hot and humid climate, almost 40% energy at such complexes is used in air-conditioning. A central Heating Ventilation and Air Conditioning (HVAC) system chills water to about 6°C, which is then circulated to each office. IITMRP has built an underground chilled water energy storage of 300 cubic meter capacity, which can store chilled water for use when needed. The only limitation is that the chilled water may have to be used within 6 to 8 hours of chilling, due to temperature losses of about 1°C taking place every two hours.

The heat transfer capacity of the designed thermal energy storage system is 17460 MJ, which is equivalent to 2.45 MWh of electrical storage. In such systems, one may be able to use multiple charge and discharge cycles per day without affecting the life of storage. The end-to-end round-trip energy-losses are about 5%.

The chilled water storage and Li-Ion Storage systems complement each other in helping IITMRP move towards 100% RE.



Total costs of delivered RE with Storage

IITM Research Park is leveraging the open-access policy to set-up 2 MW of solar and 2.1 MW of wind capacity around 100 to 300 kms away from its location, in the group-captive mode and wheel in the energy generated to its complex. The cost of RE power delivered to the complex includes RE generation costs (including transmission losses) of 5.14₵ per kWh and the transmission and distribution charges in open access mode of 0.89₵ per kWh. Besides this the utilities impose a demand charge for the peak power that a consumer may draw using its network. On the average this could work to be 1.37₵ per kWh. Thus, making the total cost at which solar and wind power is delivered to IITMRP about 7.4₵ per kWh (G).

In addition to this, we need to add the storage costs (S) per kWh. Now, a certain percentage of RE power coming into the complex may be used immediately, and only the excess RE needs to be stored and used at a later point. Assuming only 30% of energy needs to go through the storage, the average addition to the cost per unit of energy due to storage will be 0.3S. Thus, the average cost of the RE available to the Research Park directly and through storage will be as follows,

Average cost of RE = G + 0.3* S per kWh

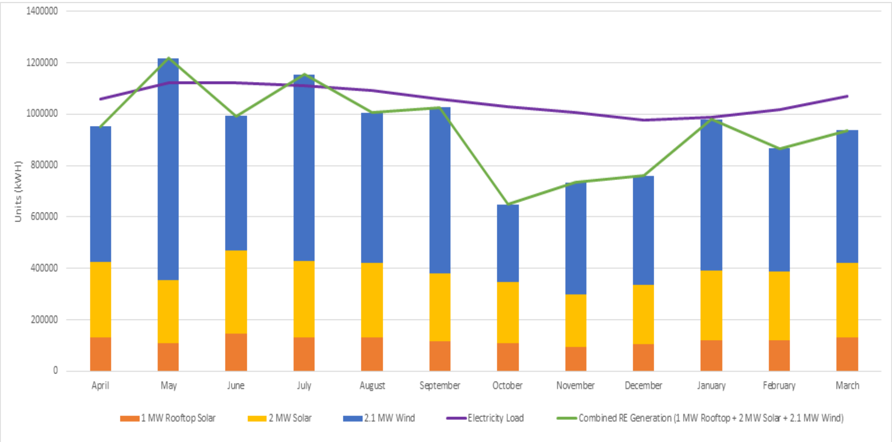
Looking at the numbers given here, this works out to 9.3₵ per kWh today. As the costs of storage is falling year after year, it is expected that even with 50% of energy going through storage, the average cost of 24X7 RE will be close to 9₵ per kWh in future. In fact, the number can be even less if the interest rates fall, the cost of solar and wind energy further declines, or transmission (wheeling) and demand charges fall.

The number of 9.3₵ per kWh compares very favourably to the cost that IITMRP pays today to utilities for its power. The current costs, including demand charges average about 15₵ per kWh for such commercial complexes. Note that as the grid-power in India is primarily carrying coal-based generation, the energy available today may be classified as primarily from thermal power. The cost advantage to commercial complexes is obvious. With careful design it can get near 100% RE to its complex and still save about a third of energy-costs that it pays today. For industrial and the residential complexes, the electricity tariffs are lower, and the cost advantage may not be as much. But if one adds the branding value that the complexes may derive out of moving towards 100% Renewable Energy, there is a strong case to move towards this.

IITM Research Park is currently carrying out this project to move towards 100% RE.

Solar and wind during days and months

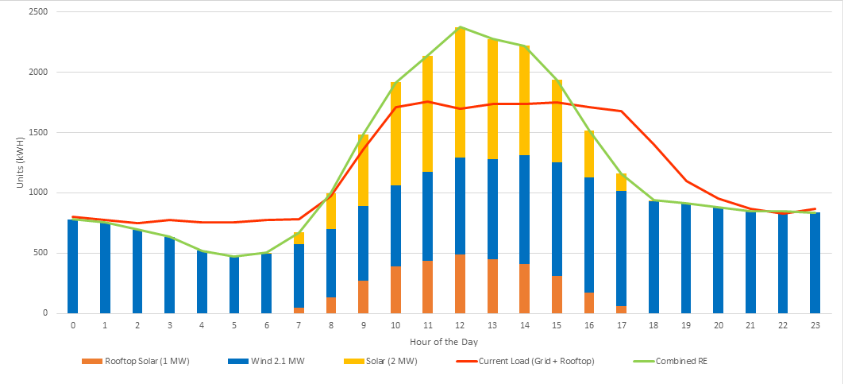
IITMRP consumes about 12 GWh of energy in a year. The usage varies slightly from month to month, varying from 970 MWh to 1100 MWh. It is currently supported by 1 MW roof-top solar, local utility grid and diesel generators, which are used when grid fails. The monthly energy generated from the captive RE plants and the roof-top solar plant are plotted in the figure along with the monthly load. As is apparent, there is a bit of excess energy available in May and July and in other months, there is a deficit. The deficit is substantial in October, November, and December, with the



peak deficit going up to 37% in October, as the wind-power generated in these months is low. The yearly deficit works out to be 11%, implying that this arrangement would make the IITMRP energy consumption 89% from Renewables. This can be improved only if a third source of Renewable Energy is available or there is a long-term large storage which can store energy over months.

Storage Size

Solar and wind energy generated varies from minute to minute and hour to hour. The total generated energy would rarely meet the IITMRP demand at any specific time and would be either in excess or in deficit. It is imperative that the excess energy is stored at IITMRP, and any deficit energy is taken from the storage. A question would be the size of the energy storage that IITMRP may need to do this. The hourly generated energy and the load is plotted in the figure for a typical weekday. The load has been adjusted by a factor so that the total energy generated matches the total demand for the day. However, as seen in the figure, there is hour to hour surplus and deficit, which has to go in and out of storage. Starting the day at midnight, the cumulative deficit peaks to 1.15 MWh and the surplus peaks to 1.47 MWh. Thus, a storage size 2.62 MWh would normally ensure that no energy is wasted. This is surprisingly small. The reason for this is that the load seems to be following similar pattern as the RE generated. The load peaks in hours when sun is out there and most of the solar energy is used directly, with a small amount of excess going into the storage. Wind in the evening and night is enough to meet most of the evening / night demand in the complex and the surplus going into storage to be used next day.



Hourly Load and available Renewable energy over 24 hours at IITMRP

This computation of storage size takes care of a variation on a typical weekday. On the weekend the demand is much less, and larger storage will be required to store the excess energy and use it on the days when demand peaks.

Conclusion

IITMRP is currently in the process of building 2 MWh Li Ion storage and getting 2.1 MW of wind energy and 2 MW of solar energy wheeled in. The storage would be expanded to about 5 MWh eventually. This plus chilled water storage of over 2.5 MWh may ensure that energy storage is available to take care of deficits and surpluses over weekdays. Weekend has substantial surplus, and the storage may have to expanded to store it and use over the weekdays. This would however not take care of deficits during the months when wind and solar energy is very low, for example October to December. As mentioned earlier, one may need a third source of Renewable Energy or some long-term storage for these months, if one is to increase the percentage of RE used further towards 100%.

As discussed earlier the total cost of the Renewable Energy and the cost of storage per kWh works out to be close to 9.3₵ per kWh, which is lower than what IITMRP pays currently for the energy from power grid. This energy is generated today primarily using coal. Thus, this effort would make a significant difference in moving IITMRP closer to 100% RE user.

India has some 40,000 such commercial complexes, which is expected only to increase in number. Building the required storage for each of these complexes and wheeling in solar and wind energy would serve multiple purposes. First, it will make the complexes close to 100% RE Complex. The cost of storage is expected to continue falling, which could then make it economically attractive for industrial complexes and large residential complexes to follow a similar approach. This could expand the RE usage in India to about 50%. Secondly, the decentralised energy management at complexes will help in energy management at national level. Thirdly, the energy storage industry will get a big boost and prepare nations better for grid-storage. As the solar and wind energy for these complexes gets generated in different parts of the country, the diversity of locations for solar and wind generation would help partially overcome RE availability in months of deficit. Policy and regulatory changes do pose a risk; however, it is unlikely to cause major challenges given the governments' commitment to expanding RE capacity and usage.

IITMRP is committed to the transition to a new and renewable energy system, and is in the process of being the first of its kind demonstration that showcases the technology readiness and economic viability of moving towards 100% RE.