Some steps for India to move towards 100% Renewable Energy

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***Abstract*—India is highly dependent on coal for producing its electricity. Even though the per-capita emissions of GHG in India is lower than that of most developed, its total emissions of GHG is close to some of the big polluters. No wonder there is an increasing pressure on India to move towards Renewable Energy (RE). India now produces solar and wind-based electricity at costs lower or comparable to that of coal-based electricity. However, while coal-based electricity generation can be increased or decreased at will to match demand, that is not the case for solar and wind-based electricity, as the quantity produced entirely depends on nature, the sun-hours and the wind-hours. Only way generation could match demand is if there are massive energy-storage systems. This paper examines how office and commercial complexes in India can take the lead in becoming a 100% RE user by installing energy storage systems and carrying out effective energy management. It would show that this can be done to reduce the cost of electricity for such complexes, while they become near-100% RE users. The industrial-complexes and housing complexes may use a similar strategy to become an RE-user and this would help move India substantially towards 100% RE. The paper examines the technology and economic challenges that have to be overcome to get there.**

I. INTRODUCTION

The source of India's electricity production is dominated by coal as evident from "Fig 1" and "Table 1". Coal-based electricity was at 1132 TWh or 71% of total electricity production in 2019; On the other hand, Renewable Energy (RE) consisting of solar, wind, geothermal and biomass is only at 162.4 TWh or at 10.2% of total electricity production with biofuels almost 25% of that. The situation has not changed drastically by March 2021, even though the installed capacity of Renewable Energy has been increasing rapidly; as shown in "Fig 2", it is at 94 GW or 24.7% of the total installed capacity of 382 GW, whereas coal-plants have a capacity of 209 GW. Even though installed capacity of RE is close to a quarter of the total, the RE generated in a year is low. This is because, the capacity utilization factor of coal plants can go as high as 85%, whereas that of solar is less than 25% and that of wind is a little above 25%. Basically, coal plants are controllable and can produce electricity when needed to match demand. However, solar and wind plants produce electricity only when the sun-shines and wind blows and is not in control of human beings. The low capacity utilization factor of these plants reflect that solar and wind energy is not available 24 x 7 and varies with the time of the day, and day of the year. The domination of coal in electricity production continues, even though coal-based electricity production has been identified today as the most polluting and most damaging in terms of its impact on climate change. Even though there is considerable pressure on India from the world community to reduce its coal-based electricity production, the results have not been very encouraging.

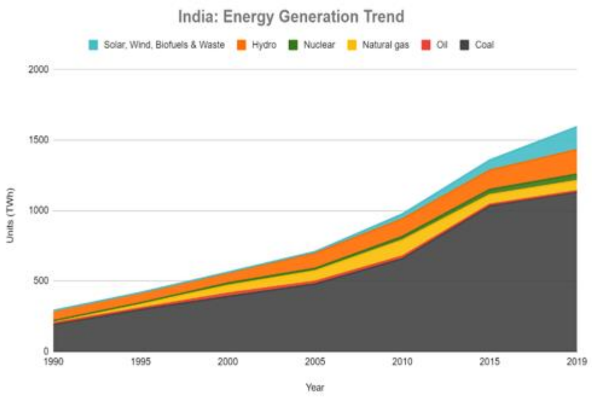

Figure 1 India's electricity production 1990-2019 India Energy Generation

Table 1 India Electricity production (GWh) in 2019

Coal	1131.66	71.01%
Oil	7.85	0.49%
Natural Gas	71.56	4.49%
Nuclear	46.47	2.92%
Hydro	173.8	10.91%
Renewable	162.36	10.19%
Total	**1593.7**	**100.00%**

This is the situation, even though the cost of Renewable energy has been falling rapidly and is today less than the cost of generating electricity from coal in India. The electricity produced from solar energy today costs about ₹2 per kWh[1] and the wind-based electricity costs about ₹2.50 per kWh (the exchange rate for Indian currency today is about ₹75 for 1 USD). On the other hand, while the older coal plants produce electricity at a total cost of about ₹2.50 per kWh, the newer plants' electricity costs may touch about ₹4 per kWh, largely due to the increased cost of imported coal and due to the equipment installed to meet emission regulation standards of today. The question is why India can't switch over fully to Renewable energy. The answer is again that the Renewable energy plants generate electricity when sun shines and wind blows and is not controllable to meet energy demand as and when needed, whereas the electricity produced from the coal plants can be increased or decreased (with some lag) to follow demand.

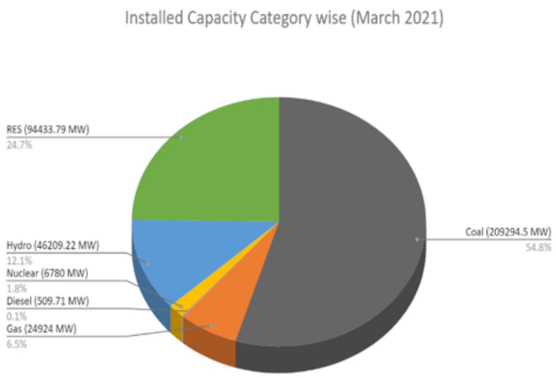

Figure 2 Installed Power-production Capacity Source-wise in March 2021; Total capacity of 382 GW https://powermin.gov.in/en/content/power-sector-glance-all-india

II. Energy Storage Option

Energy storage provides the much-needed flexibility to the use of electricity as per the actual demand. Today, we have several energy storage mechanisms that are available. Depending upon the requirement, type of technology[2], and economics, one may select from options such as, battery energy storage[3,8], pumped hydroelectric storage[4], Large flywheels[5,6,7], thermal energy storage[8], compressed gas energy storage[8] or hydrogen-based energy storage[9,10] amongst others. Each one has its advantages and disadvantages and are in various stages of development and deployment. Pumped hydroelectric or compressed gas-based energy storage involves huge capital investment due to its sheer size and is most suitable to be placed at electricity generation end; the number of cycles it offers is relatively high and it has a longer life span. Battery energy storage or hydrogen-based electricity storage systems like fuel cells are generally more modular in design and can also be deployed at relatively smaller sizes. Energy storage systems from these sources can be placed both on the generation side as well as the consumption side. The response time of battery energy storage systems is very low and widely used for instantaneous delivery of power during peak demand, and black outs. However, the lifetime is limited to 8 to 15 years for most types of battery storage systems. Recent advancements in various cell chemistries, especially in Li ion-based energy storage systems has brought down costs significantly, improved calendar life and number of cycles, making it a more favourable choice for both large and small sized energy storage systems. Due to the continuous and cyclic variability of generation of renewable energy sources like solar and wind, and the need to meet peak demand at smaller time scales, the mechanical flywheel energy storage system has also worked out to be a good option. Cycle life tends to be much more than 100000. However, complexity involved in friction reduction technology like vacuum chamber, air or magnetic frictionless bearing makes the system design, operation, and maintenance difficult. Thermal energy storage systems at the consumer end on the other hand are useful wherever there is a need for a Heating Ventilation and Air Conditioning (HVAC) system. In India, almost 40% of the total energy requirements of commercial buildings are for HVAC. In case of excess RE, a thermal storage system can precondition and store energy in the form of working fluid of thermal energy storage, and this in turn can be used whenever the renewable energy is in deficit or absent, thus making it an attractive form of energy storage. Compressed gas storage is another option, but it involves storing of compressed gases underground and is still in the R&D stage.

Li Ion Battery Storage is proving to be most cost-effective with continuously falling costs[11] and is highly suitable when one wants to use the storage at the consumption point, rather than at generation point. Two kinds of cells are being widely used today. One is a higher-end NMC cell with Si in Graphite anode (Cell A) giving about 7000 cycles with the battery cost under ₹20K per kWh for a one MWh battery or larger. The other is LTO cells (Cell B) with about 15000 cycles and battery cost at little less than ₹40K per kWh.

The effective cost of usage of such batteries involves computation of depreciation (over the life of the battery) and interest costs of the battery for each cycle of usage. This will depend on capital cost of the battery, life cycle, the number of cycles used per day as well as the interest rate paid. "Fig 3" shows the computed total cost of usage of battery for each cycle depends highly on (i) number of cycles used per day and (ii) interest rates. One may conclude from the figure that costs will come down considerably if battery is used for more than one cycle per day. Similarly, the interest rates play a major role in deciding on the cost of usage of the battery. For example, the cost of LTO battery goes up from ₹4 per kWh at 2% interest rate (prevalent in the West) to ₹12 per kWh at 10% interest (prevalent in India and other emerging countries countries).

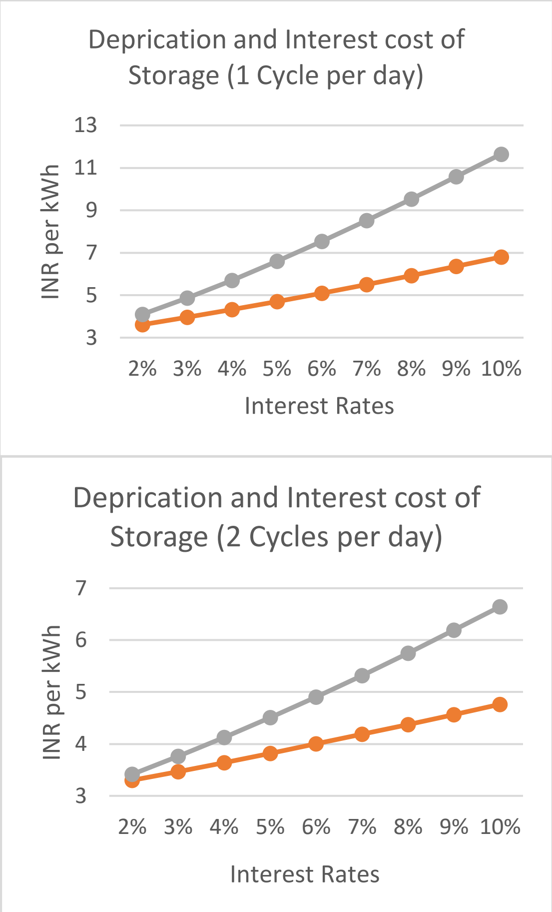

Figure 3 Depreciation and Interest Cost per kWh at different interest rates for single cycle and dual cycles per day usage. Orange line are for Cell A and Gray lines for Cell B.

This is of huge significance and the storage costs would sky-rocket if interest rates are high. One therefore has to ensure that the capital costs are low, even if the number of cycles are lower; Cell A or high-end NMS batteries thus scores much better than LTO batteries for countries of emerging markets. Similarly, when battery packs are made using cells in these countries, all attempts need to be made to reduce the initial capital costs.

Thus, the effective cost of storage in countries like India (at 10% interest) works out to be ₹7 per kWh for a single cycle per day and ₹5.75 per kWh in case of two cycles. Judicious use of solar and wind may get us to have 1.5 cycles to 2 cycles per day; for the computations in this paper we would assume that cost of storage today is about ₹6 per kWh.

Again, for hot countries like India, chilled water storage works out to be very cost effective. These countries use considerable air-conditioning, consuming as much as 40% of total electricity consumed in large buildings. The centralised HVAC systems generally use centralised air-conditioning, which chills water at a central facility, which is circulated throughout the complex to cool air in individual rooms. It is easy and cost effective to build a chilled water storage system (with some thermal insulation), where water can be chilled earlier in the day whenever renewable energy is available in excess and stored for use when the renewable energy available is less than the demand. The development of such chilled water storage is largely a one-time capital cost offering very large cycle and calendar life, which can provide a very cost-effective means of storage.

III. Commercial Complexes and Wheeling in RE

Commercial complexes, industrial complexes, educational complexes, and housing complexes consume a significant portion of electricity in all societies. It is possible to get them to continuously increase consumption of Renewable energy as opposed to conventional fossil-fuel based energy. While they may use energy from roof-top solar, the limited roof-top space that they have is unlikely to give them a high percentage of RE and they would still be primarily dependent on grid-based electricity. Fortunately, India has a unique power-transmission and wheeling policy under its Open Access mechanism[12], through which such complexes may generate solar and wind energy under a group-captive policy where they invest and set up generation of RE away from their complexes and wheel in the energy to their complex. This will get them to increase their usage of RE. The only limitation would be to match the supply (wheeled in and roof-top solar energy) and the demand in the complex at each instance of time. This problem could be overcome by using the right-size of energy storage at such complexes.

The commercial complexes in India are large in number (some 40,000), which are increasing rapidly and projected to total up to 19 billion square feet by 2030. They get grid-electricity at a high cost (about ₹11 per kWh including the costs of energy from diesel generators that they use when they have power-cuts) and can reduce the cost of electricity that they consume if they have rooftop solar, wheeled-in RE, and build energy-storage on their campus and manage them well to ensure minimum costs while delivering 24x7 reliable power.

IIT Madras Research Park (IITMRP) is one such complex with 1.2 million square feet and will consume about 40 MWh of electricity every day, when fully occupied. The total cost of electricity at the current rate of ₹11 per kWh would therefore amount to ₹440,000 per day or about ₹13.2 million per month. IITMRP has a 1 MW roof-top solar generating just about 4 MWh a day. It is now in the process of procuring Renewable energy from 3 MW of solar and 1 MW of wind. The cost of solar power (including T&D losses) obtained under the group-captive scheme will be about ₹3.50 per kWh and there will be an open access charge of about ₹0.75 per kWh. For 1 MW wind, this cost could go up to ₹4.10 per kWh with open access charge remaining the same. Further, the power distribution company (DISCOM) adds a demand charge based on peak power that the client draws. If the management system manages to keep the peaks low, this would work out to be a little over ₹1 per kWh. Thus, the total cost of electricity delivered at IITMRP complex will be ₹5.25 per kWh for solar and ₹5.85 for wind.

The complex should be able to consume the delivered RE directly about 70% of the time, if the energy management system (EMS) is designed to use storage to a minimal extent while maximising usage of RE. For 30% time, it will have to store excess RE and use it later in the day when RE available is in deficit of the demand. The factor is justified as the solar energy is available in the daytime when there is high consumption. Only the excess need to go to storage. Wind energy is available at different times of the day and part of it may be stored. Thus, the effective cost of storage for RE will add 0.3*₹6 or ₹1.8 per kWh to the cost of delivered RE. Thus, the usage cost of solar and wind energy would be ₹7.05 and ₹7.65 per kWh respectively, and this would be available to the user 24 x7. This compares quite favorably to the ₹11 that IITMRP spends today for power. Thus, moving to RE becomes not only a desirable goal, but would also save money. The IITM Research Park is currently working on implementing these solutions and aims to be a pilot demonstration site, which would be a first-of-its kind showcase project in India. **Aligning the climate goal to saving money is one of the best ways to combat climate change**.

The approach could be easily adopted by other commercial complexes in India. Note that moving towards 100% Renewable energy is also of brand-value to such commercial complexes. One may have to fine-tune some of the policies towards usage of the wheeled-in energy. But as this would promote RE in India and move India towards 100% Renewable energy, one should be able to persuade the government and the regulators.

The commercial complexes in the country today consumes only 8% of total electricity in India, whereas the Industrial sector consumes 43%[13], and even Government and Educational complexes consume substantially. In addition, multi-storied housing complexes, especially the middle and upper middle-class urban homes today consume a growing share of the 23% energy used by residential sector. Moving all of them towards 100% RE by using such an approach is indeed possible; however, the cost benefit may not be as large as their electricity tariff today is lower than that of commercial complexes. As RE usage expands, one may be able to rationalize the costs to a significant extent. There is no reason that the cost paid for solar and wind energy generation be upwards of ₹4 per kWh, when large solar and wind generation tenders yield a cost between ₹2 per kWh to ₹2.50 per kWh today. Similarly, today's wheeling and transport charges (including demand charges) of about ₹1.75 per kWh can be reduced. Policy interventions to bring down these costs closer to ₹1 per kWh for RE based procurement would further help in advancing the transition towards 100% RE. Thus, it is possible for the approach to make business sense. At the same time, the usage of storage at the generation end, especially for solar and wind generation plants, would increase so as to enable the RE to meet the varying grid demand. This would further help take India rapidly towards100% RE.

IV. AVAILABILITY OF SOLAR AND WIND IN INDIA

The question of the size of the energy storage in a Complex has not been dealt with so far. The storage is supposed to fill the temporal gap between RE supply and Building Complex demand of electricity. The gap could be of two kinds, one is due to time of the day mismatch between the supply and the demand. Solar energy is available only in the daytime as shown in "Fig 4", whereas the peak consumption would also be after sunset. On the other hand, as shown in the "Fig 4", typical wind profile peaks in the evening. This short-term gap can be easily filled by the kind of storage that we have discussed in this paper; using the RE availability and demand at different times of the day, the size of the energy storage could be estimated. Then the energy management system could be programmed to appropriately control the inlets and outlets of the storage to ensure there is no energy loss. The other kind of gap would be in terms of weeks and months. For example, wind energy peaks in certain months (May to August in India) as shown in "Fig 5", giving surplus electricity during the time. In other months (November to April in India), the electricity generation is rather low, creating a deficit situation.

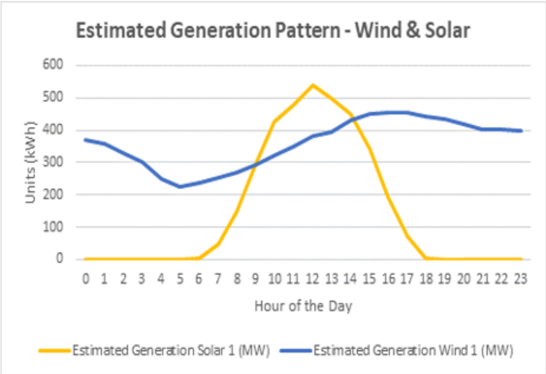

Figure 4 Solar and Wind energy available over 24 hours on a typical day

Solar energy however varies much less and is unlikely to create this long-term deficit. This long-term deficit is far more difficult to be bridged by such battery storage systems. For days, the energy generated could be much higher than the demand. One would need long-term storage which will store energy and could be used after several weeks or a few months. Additionally, since the surplus, especially for wind energy, will continue for several months, the storage needs to be large. Battery Storage systems are not suitable for such applications. One may have to use pumped storage, where the water-tanks at height as well ground are of rather large size. Alternatively, one may be able to use hydrogen or other forms of storage once the technology matures and become usable.

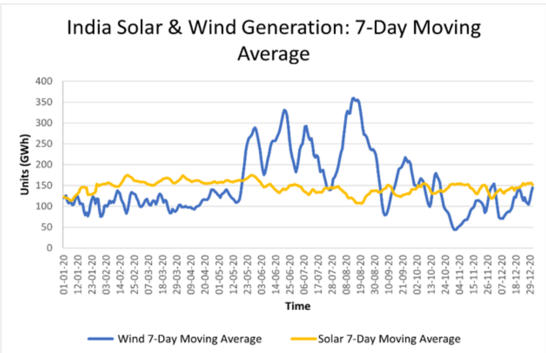

Figure 5 Variance of Solar and Wind generation over the year in India for 2020, with wind capacity at 38 GW and for solar at 32.6 GW

Combining solar and wind here does not help as much, as is evident from “Fig 5”, as solar energy dips are not large enough to compensate for the peaks of wind energy. Ideally one needs a third energy source in such situations. Of course, grid energy (which may be largely coal-based energy today) could be the third source, but would defeat the goal to move towards 100% RE. If nuclear energy is available, it would be an ideal third source. One may be able to also use biofuels to some extent, but it’s scaling currently remains difficult.

V. Conclusion

India is today the third highest contributor[14] to GHG emissions. While China, United States and contributes 28%, 15% respectively, India’s contribution is 7% of the total emissions. On a per capita basis India ranks very low in emissions as compared to most developed as well as developing countries. It is unfair to target India, while developed countries, who created the problem in the first place and have very high per capita emissions, move slowly. Yet, even while India has resisted this unfair pressure, it needs to remain cognizant that it is a rapidly growing economy. With growth rate in the range of 6% to 8%, leading to a steady increase in the income of its middle and upper middle classes, they would increasingly consume more energy going forward. In addition, the use of air-conditioners is already growing rapidly, further increasing its per capita energy consumption. Thus, India needs to move towards clean energy today rather than tomorrow. This would enable it to take up the leadership role in climate change initiatives, and demand more from the developed countries. Its argument of minimal per-capita emissions would be on a stronger footing as it does substantially to reduce CO_2 emissions in its production of electricity.

The paper presents that the Indian corporate sector can play a lead role in making their office-complexes fully green using renewable energy, and in the process also reduce its cost of electricity. Not often do we find programs which do the right things, make economic sense, and also set an example for others to follow. As discussed earlier, supporting policy initiatives will be required so that the cost of generation of renewable energy and the cost of transmission and wheeling of electricity to these complexes may be further optimized. This will make moving to RE not only a desirable goal but also a financially beneficial one. **Aligning the climate goal to saving money is one of the best ways to combat climate change**.

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