installed capacity of renewables become dominant even within next 20 years, all the fossil units and even nuclear units will have to ramp up or down their power output on daily basis to meet the generation gap as decided by a nationwide coordinated control centre. Necessary modifications in the design of such large new units for scheduled load follow operation should be possible. The spinning reserve needed for grid frequency control can be augmented by pumped storage hydro plants and grid scale storage batteries that are becoming commercially available. Additional reactive compensation needed in the form of static VAR systems and synchronous condensers to ensure a satisfactory voltage profile over the grid can be established by detailed load flow studies for all anticipated operating situations. As the necessary models and software needed for optimal power dispatch on hour to hour basis across the entire country are readily available, there should be no insurmountable difficulty to satisfy the energy needs of the country at a rationally determined minimum cost[4].

Planning for time periods beyond 2040 would be necessarily sketchy because of the difficulties in forecasting the techno-commercial options available that time.

1. Grover, R. B., *Curr. Sci*., 2020, **119**(12), 1910–1918.
2. Report of 19th Electric Power Survey of India by Econometric Method, January 2020, Power Survey and Load Forecasting Division; cea.nic.in
3. hdr.undp.org
4. Report on optimal generation capacity mix for 2029–30, August 2019; cea.nic.in

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Response

Transition to a low-carbon electricity mix

The Paris Agreement was adopted in 2015 by 196 Parties and aims to limit global warming to well below 2, preferably 1.5 Celsius, compared to pre-industrial levels. To achieve this goal, Parties including India announced Intended Nationally Determined Contributions and in recent months there is a clamour for reaching 'net zero' by the middle of this century. Many studies aimed at reducing carbon emissions are being pursued by academics such as the 'Carbon mitigation initiative' by Princeton University[1]. Based on these studies, certain narratives are prevalent in media. Some narratives transport conclusions derived in a certain context to an altogether different context without looking at issues of applicability. An oft-repeated example is to pronounce that solar and wind can meet all electricity requirements without looking at the density of population of a country. Another common narrative is to compare tariff based on 'Levelised cost of electricity' generation, a metric which does not account for intermittency. To provide evidence-supported perspective to readers, I enumerated some narratives and discussed them in detail in a paper[2].

Thangasamy, although while generally agreeing to my approach, alludes to the practice of adopting a planning horizon of 20 years for capacity addition. However, my paper nowhere gives annual capacity targets; it provides guidance for transition to a low-carbon electricity-mix. The energy-mix and electricity-mix are intertwined and the present energy-mix has been built over almost three centuries. It will take at least half a century to transition to a new energy-mix.

Regarding the correlation between Human Development Index (HDI) and Per Capita Per Annum Electricity Consumption (PCPAEC), he alludes to a difference between a country like India and the industrialized world without providing any supporting argument. In a connected world, differences are not sustainable. One can note rising electricity consumption in India and its neighbourhood. In Singapore, an example not cited in my paper as it is an urban space, PCPAEC is at the same level as the average of countries comprising OECD. The plot of HDI versus PCPAEC of various countries does show large scatter as it includes countries with large differences in population density, percentage of population living in urban spaces, resource endowments, climatic conditions, geographical area and geopolitical situation. However, the trend of first sharp increase in HDI followed by approaching a value of one asymptotically is unambiguous. A detailed analysis for arriving at a more precise target would rob my analysis of its simplicity. A change of 10–20% from the target of 5000 kW-hour PCPAEC does not change the conclusions of my paper. Considering that the share of electricity in the total final consumption of energy is rising due to convenience of use and minimum environmental effect at the point of use, the proposed target is conservative.

Reference made by Thangasamy to pumped storage and its use in reactive compensation is appreciated, but unfortunately such storage sites in the country are limited. Along with reactive power, lack of mechanical inertia is another issue that needs to be addressed in the case of solar power. Storage and other system effects are not likely to make electricity from wind and solar inexpensive for the consumers as already experienced by countries like Germany. Despite advances in forecasting in generation by solar and wind, reliability remains an issue as demonstrated by rolling blackouts in recent past in California and Australia.

The present approach of aggregating plans, made independently by various ministries and departments sitting in their silos, has to be replaced by an approach based on integrated analysis which factors in availability of resources and characteristics of technologies including indigenous manufacturing capability.

UK is perhaps the first major economy to release a White Paper[3] for transition to a net zero future. They have analysed 7000 different electricity mixes in 2050, for two different levels of demand and flexibility, and 27 different technology cost combinations. India needs to launch a similar effort to decarbonize without compromising the dreams of an aspirational India.

1. Carbon Mitigation Initiative, Princeton University; https://cmi.princeton.edu/wp-content/uploads/2020/01/wedges-teachers_guide.pdf (accessed on 30 January 2021).
2. Grover, R. B., *Curr. Sci*., 2020, **119**(12), 1910–1918.
3. The Energy White Paper: Powering our Net Zero Future, HM Government, December 2020.

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