An examination of the narratives about the electricity sector

*R. B. Grover**

I enumerate some of the narratives about the electricity sector in India and examine them in detail. Coal is a major source for energy in India and forms a significant part of India's present electricity mix, while the share of renewable energy sources is increasing. Share of hydro has declined over the years, and the share of nuclear is set to rise as several reactors are under construction and more have been approved. The paper comments on limitations of using levelized cost of electricity generation as a metric for comparing different technology options and suggests replacing it by an approach based on system modelling. Electricity demand is rising, and renewable energy sources and large hydro cannot meet the total projected demand. Switching over to a mix that addresses environment concerns has a cost attached to it and these costs need to be recognized and paid. After an examination of narratives, the paper ends with detailed observations about the electricity sector with the objective of providing evidence-supported perspective to public and also inputs for the formulation of policies.

Keywords: Electricity demand growth, EROI, grid level costs, health externalities, LCOE, security of supply.

NARRATIVES have a powerful role in any society, but they could be based on facts or perceptions, or be planted by interest groups, or might result from a serendipitous sequence of events which is difficult to trace back. Irrespective of the source of origin, narratives do influence policy formulation and decision making. After a brief introduction, I enumerate some narratives about the electricity sector in India and examine them in detail.

India is a large electricity producer, but per capita electricity consumption at about 1200 kWhr (called units hereafter) in 2018–19 is significantly lower than the world average which has been above 3000 units since 2014. Major share (80.5%) of electricity is produced by fossil fuels, mostly coal, 8.7% by large hydro, 2.4% by nuclear and the balance 8.4% by Renewable Energy Sources (RES)[1]. Large hydro accounted for about 40% of electricity generation in late seventies. However, to meet rising electricity demand, more and more coal fired plants were set up making coal as the mainstay of electricity generation in India. Over-dependence on coal has implications for environment and climate change. Because of large share of coal in electricity generation, CO_2 emissions by India's electricity generation sector[2], at 718 gCO_2/kWh in 2017, were 48% above the global average of 485 gCO_2/kWh. This is a cause for concern and needs examination particularly when demand for electricity is growing. Cumulative Average Growth Rate (CAGR) for electricity generation[1] for the period 2009–10 to 2018–19 was 5.49%. Data also reveals that generation by non-utilities in recent years has been substantial – around 12%. Generation during 2019–20 is likely to be only marginally above the previous year. So far data[3] about generation from utilities is available and is marginally above (0.26%) the generation in 2019–20.

In view of importance of electricity, it is a topic for discussion in media, seminars by researchers in the field and industry, and public in general. One can enumerate the following as some of the narratives about the electricity sector in India.

1. Growth in electricity demand is sluggish and RES can meet most of the demand.
2. Increase in the share of RES in the electricity mix will bring down tariff for the consumers.
3. There are no bio-physical constraints to the growth of electricity from various sources.
4. Coal-fired power plants are a major contributor to carbon emissions and should be phased out as soon as possible.
5. There are no safety issues in electricity generation technologies other than nuclear.

This paper discusses all these narratives with a view to provide an evidence-supported perspective to public, and also inputs for the formulation of policies.

The author is in Homi Bhabha National Institute, Mumbai 400 094, India.
*e-mail: rbgrover@hbni.ac.in

Narrative 1: Role of RES

A variety of methods have been developed for forecasting electricity demand. All approaches depend on a set of assumptions, but do provide some estimates about year wise growth, for example see the study by Ali[4]. Rather than looking for year-wise additions to the installed capacity, a simplified approach is followed here to arrive at requirements of electricity after three to four decades. For this purpose, one can examine the correlation between Human Development Index (HDI) and per capita electricity consumption as illustrated in Figure 1 and dots in the figure correspond to various countries. HDI is a composite indicator for assessing the well-being of citizens of a country and to achieve a high HDI that is about 0.9, it is necessary to have a per capita electricity consumption of about 5000 units per annum. The correlation between HDI and electricity consumption has been and will continue to evolve due to several factors. Increase in energy efficiency will help in achieving a given HDI at a lower value of electricity consumption. Structural changes in the energy sector like increasing use of electricity in transport, industry and even for cooking are expected to lead to an increase in the share of electricity in the Total Final Consumption (TFC), which is the sum of consumption of energy from various sources by different end-use sectors and includes non-energy use. These changes will call for a higher per capita electricity consumption for a given HDI. According to estimate by IAEA[5], global average share of electricity in TFC in 2018 was18.8%, and it will increase to 26.1% in 2050. These percentages do not represent total primary energy used to produce electricity. While for converting thermal energy to electricity energy, the conversion efficiency is about 33%, no such conversion is involved in case of hydro, solar and wind. Until 2016, IAEA[6] was reporting data based on an approach that took cognisance of this conversion, and percentages then reported were 37.4% for 2015 and 49% for 2050.

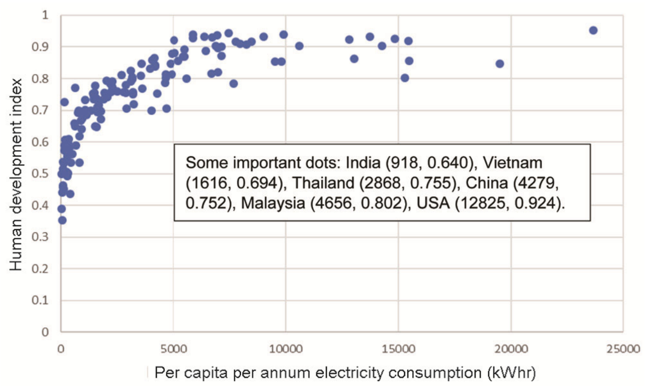

Figure 1. Human development index versus electricity consumption for different countries. Data for electricity consumption is from ref. 35. Data for HDI is from ref. 36.

In short, the correlation depicted by data in Figure 1 can shift, but one can still use 5000 kWh per capita per annum for planning purpose. Countries in the neighbourhood of India and having similar climate, like Malaysia and Thailand, are fast approaching this number.

Can India remain far behind?

To provide a decent standard of living to its citizens, central and state governments together have to plan to build enough generating capacity so that by about the middle of this century, per capita per annum consumption in India rises to 5000 units. Assuming that India's population will peak at about 1.6 billion (this is a low estimate and is being used to arrive at a conservative estimate for required electricity generation), and it will be possible to bring down transmission and distribution losses to technically lowest achievable level of about 7%, India will need to generate 8700 billion units per annum. This is more than five times the generation (from utilities, non-utilities and RES) in 2019–20, which was about 1600 billion units. IEA has forecast that demand in India[2] will rise to only 3700 BU by 2040. It translates into a CAGR of about 4.3%, while the CAGR during 2009–10 to 2018–19 was 5.49%. Assuming a long-term CAGR for electricity generation to be 5%, India will reach the target of 8700 BU in about 35 years.

We have to examine the potential and characteristics of various technology options to guide further evolution of electricity mix to achieve this target. According to available estimates[7], India has a wind potential of about 300 GW at a hub height of 100 m, solar potential of ~750 GW, assuming 3% wasteland is made available, and bio-energy potential of 25 GW. Assuming a plant load factor of 20%, all these sources can provide about 1900 billion units per annum. Large hydro generated 156 billion units during 2019–20. India still has untapped hydro potential and that should be harnessed as soon as possible. Assuming full potential of RES and large hydro is harnessed, total generation from hydro, solar, wind and bio-energy cannot exceed about a quarter of target demand of 8700 billion units. The balance has to be provided by nuclear and coal. Therefore, all technology options, including coal, have to continue to be a part of India's electricity mix.

The observation about continued use of all technology options is opposite to the views expressed by some others who opine that demand for electricity can be met with RES supported by energy efficiency and social norms promoting frugality[8–10]. While significant gains in energy efficiency have been achieved, frugality in energy usage is nowhere in sight.

Government of India has launched several initiatives including setting up a company called Energy Efficiency Services Limited (EESL), which is piloting programmes like energy efficient buildings, smart meters, energy efficient air-conditioners, electric vehicles, etc. Bureau of Energy Efficiency (BEE), a statutory body, is setting up standards for energy efficiency. Star labelling programme launched by BEE is an effective way to promote energy efficient appliances. While all these are successful initiatives, one has to also examine rebound effect, which refers to the reduction in expected gains from new technologies that increase the efficiency of resource use, because of behavioural or other systemic responses. For example, the programme of the Government of India to promote use of LEDs has been successful, but one can see that every room in a middle-class residence now has multiple light sources in place of a single bulb.

Frugality would require lifestyle changes and overhaul of economic systems, and both are challenging. Speaking specifically about India, demand for electrical appliances will continuously increase as India has one of the lowest appliance penetration rates in the world[2]. According to trade journals, penetration of refrigerators[11] in India, a tropical country, was 27.3% in 2016 and is projected to rise to 47.5% in 2026. Rising demand for space cooling has prompted the Government of India to announce a 'Cooling Action Plan' and India is the only country in the world to do so. Households owning an air-conditioner are set to increase[2] from 4.5% in 2017 to 31% in 2030, and 67% in 2040. Number of air-conditioning units in 2050 could increase to one billion. Cooling is needed not only for personal comfort, but also for cold storages which are essential to preserve perishable agricultural produce. In addition to requirements of electricity for cooling, electricity requirements for buildings is set to rise significantly as about 75% of the stock of buildings expected to be standing in India in 2030 is yet to be built[2]. All this implies a rising demand for electricity in India.

Slowing down of increase in electricity generation in recent years and almost no increase in the last fiscal is not due to lack of need for more electricity, but because of overdue policy reforms. There is no monitoring of DISCOMs for reliability of supply[2]. They frequently resort to load shedding to manage demand. DISCOMs have no incentive to purchase electricity from power exchanges, as for them more supply means more under-recoveries. As a result, back-up solutions, that is inverters mostly based on lead-acid batteries, are in demand as indicated by their increasing sales. India UPS market[12] is forecast to grow at a CAGR of more than 9% during 2019–2023. Such solutions are expensive, but have become necessary for tier-2 and tier-3 cities. Kerosene lamps still continue to be used in rural areas for lighting as electric supply is not available for long durations. All this and large share of non-utilities in power generation referred to earlier reveals the existence of a large pent-up demand.

The government has taken note of inefficiencies of DISCOMs as announced by the Finance Minister in her press conference on 16 May 2020. Announcement referred to a tariff policy that will include mandating DISCOMs to ensure adequate power so as to avoid load-shedding. This initiative will help in meeting pent-up demand.

In short, demand for electricity has been and will keep on rising. India should be generating about 8700 BU per annum by about the middle of this century. Appropriate policy interventions need to be made now to ensure that the evolving generation mix is environment friendly, and has enough diversity to provide security to consumers. Opinions expressed with regard to economic recovery following ongoing COVID-19 led slowdown are quite diverse, but do include a V-shaped recovery and no long-term stagnation. A reliable power supply is a must to make a V-shaped recovery possible.

The above examination of narrative 1 point to a growing electricity demand during the coming decades and total estimated potential of RES including large hydro is not sufficient to meet the projected demand.

Narrative 2: Integrating RES to the grid

In the ongoing general discourse on the use of RES for generation of electricity, an impression has been created that electricity from solar and wind will be very cost-competitive. This impression is the result of two technicalities: one is the use of a wrong metric that is Levelized Cost of Electricity (LCOE) generation for comparison, and the second is due to not explicitly bringing grid-level costs in the general discourse for calculation of tariff. Grid-level costs arise from the fact that electricity is generated by a power plant, and to reach consumers it has to pass through a transmission and distribution network. Important elements of an electric supply system are electricity generating plants and associated fuel supply chain, electrical substations for stepping voltage up for transmission and down for distribution, high-voltage transmission lines, a distribution network, and despatch centres for managing transmission and distribution to ensure that generation matches demand, and deviation in grid parameters is within acceptable limits.

Implications of both technicalities on tariff are well known to experts, but are yet to become a part of general discourse. Also they are yet to be fully accounted in policies formulated to determine tariff. We will examine both technicalities one by one.

Limitations of estimates based on LCOE

The consumer-end cost of electricity is not the same as the generator-end cost due to the transmission and distribution system that lies in between the two. For comparison of cost of generation from various technology options, a popular method is the LCOE generation. It is simple and easy to use, but compares only generator-end costs. It is equal to lifetime costs (present value of the total cost of building, and operating a power plant over an assumed lifetime) divided by lifetime energy production. It provides a good basis for comparing technology options having different life spans. It was devised before the advent of RES and therefore, has no parameter to account for intermittency. Hence, it cannot capture additional balancing costs imposed by intermittency. Energy sources used earlier that is coal, nuclear and large hydro are available round the clock, and lack of a parameter to account for intermittency in the LCOE method was inconsequential for their inter-comparison. When aiming to integrate more intermittent RES to the grid, continued use of LCOE as a metric for comparison of technology options is erroneous. LCOE tends to overestimate the economic efficiency of RES and extent of overestimate increases with increase in their penetration[13].

Attempts made by energy economists to replace LCOE by a simple method have not been successful, and complete system modelling is the only way to determine overall benefit and loss to the electric system from integrating new capacity[14]. Given the cost of creating new capacity and integrating it into the grid, modelling can identify benefits of new capacity and loss to existing generators because of integrating new capacity. Adding any new intermittent capacity distorts the load profile of residual generators that can provide electricity 24×7, reduces their plant load factor and also results in wear and tear of the machinery. We will further examine integration costs while discussing grid level costs.

From remarks made during seminars by experts associated with electricity industry, one senses a reluctance to move away from LCOE as it is embedded in all industry practices, and any revision of practices is a tortuous task.

Grid level costs

Cost at the generator-end are plant level costs and its components are: cost of servicing the capital invested in setting up the plant, and cost of generation (fuel, operation and maintenance). Next are the grid level cost, which consist of grid connection, grid extension and reinforcement, short-term balancing costs, and long-term costs for maintaining adequate back-up supply.

Peak load in India normally occurs in the evening when solar is not available. The manager of the electricity system has to ensure that available installed capacity is adequate to meet the peak load. Therefore, total capital invested in the electricity system will remain the same whether solar is or is not a part of the electricity mix. When it is a part of the electricity mix, its influence is to reduce the capacity factor of plants that can operate 24 × 7. Table 1 gives data in support of this remark.

As on 31 March 2020, total installed capacity in despatchable power plants in the country was 283.079 GW, and installed capacity based on RES was 87.028 GW. Peak demand met during the year was 182.533 GW, which is only 64.5% of despatchable installed capacity. Therefore, if RES was not there, despatchable generators could have met the demand by increase in plant load factor. Data on plant load factors of previous years clearly indicate that despatchable generators are capable of working at higher plant load factors. This indicates that investment in despatchable generators in not being fully utilized. This has a positive as it means less CO_2 emissions, but it also has a negative as it has resulted in poor return on capital invested in coal-fired power plants. This is a huge financial burden as the cost of capital in India is very high. Consequences of poor financial health have to be ultimately borne by the citizens of the country. This leads one to conclude that while increasing RES-based installed capacity is desirable to address environmental concerns, it comes with a cost. Not recognizing these costs will lead to wrong policy decisions.

RES are distributed sources and so cost of grid extension is quite significant, and grid is not used all the time as in the case of sources that are available 24 × 7.

Table 1. Select data from Ministry of Power[3]

(a) Installed capacity as on 31 March 2020

Fuel	MW	% of total
Total thermal	230,600	62.8%
Coal	198,525	54.2%
Lignite	6,610	1.7%
Gas	24,937	6.9%
Diesel	510	0.1%
Hydro	45,699	12.4%
Nuclear	6,780	1.9%
Total of despatchable installed capacity	283,079	76.5%
RES	87.028	23.5%
Total installed capacity	370.106	100%

(b) Peak load met = 182,533 MW (64.5% of despatchable installed capacity)

(c) The PLF (coal and lignite based) from 2009–10 to 2019–20

		Sector-wise PLF (%)		
Year	PLF (%)	Central	State	Private
2009–10	77.5	85.5	70.9	83.9
2010–11	75.1	85.1	66.7	80.7
2011–12	73.3	82.1	68.0	69.5
2012–13	69.9	79.2	65.6	64.1
2013–14	65.60	76.10	59.10	62.10
2014–15	64.46	73.96	59.83	60.58
2015–16	62.29	72.52	55.41	60.49
2016–17	59.88	71.98	54.35	55.73
2017–18	60.67	72.35	56.83	55.32
2018–19	61.07	72.64	57.81	55.24
2019–20	56.08	65.36	50.26	54.73

Grid level costs have been studied in detail by Nuclear Energy Agency of OECD and it is found that the intermittency of RES has a strong negative influence on grid level costs[15]. As indicated while discussing LCOE, grid level costs increase as level of penetration of RES increases. Cost of electricity for consumers in Germany has increased after integration of more RES[16], and the notion that solar and wind will usher in an era of cheap electricity is not based on experience elsewhere.

The grid level costs arising from intermittency of RES can be mitigated with the installation of storage devices such as pumped storage or batteries, or by using large hydro plants for load following. Pumped storage is a mature technology, and is cost-effective for long-duration storage, but needs appropriate sites for implementation. Cost of lithium-based batteries is coming down, but is still very high. Ongoing research on 'Flow Batteries' might help in reducing the cost significantly and recent results from the point of long-duration storage are encouraging[17]. To get maximum advantage from RES, research on battery technology needs to be heavily funded in India.

There is a cost attached to storage and has two components: (i) capital cost of creating storage, and (ii) operating cost including round trip efficiency which for many technology options is significantly less than 100%. From policy perspective, it is desirable to recognize the need for a solution and the associated cost, and one can go in for any of the solutions based on cost-benefit analysis.

In addition to storage, hydro plants could also be used for load following and should be compensated for resulting wear and tear. Another approach could be to set up gas-based peaking plants, but gas supply in India is not sufficient to power such plants. One can also attempt demand management with the help of smart meters and appropriate price incentives. The option of operating RES in 'full flexibility mode' also needs to be examined as it has been found to provide operational cost savings[2].

All possible solutions namely storage, load following by hydro, or operating coal-fired plant at low capacity factor, have an attached cost. Doing system analysis is the only option to quantify and attribute all costs. Not doing so implies subsidizing some technologies without even knowing which one are being subsidized and to what extent.

The above examination of narrative 2 points to a need for change in practice of electricity industry to use LCOE to arrive at decisions about new capacity addition; they should go in for an approach based on complete system analysis. Based on academic studies and experience of other countries, it is obvious that based on the present storage technologies, integration of RES to the grid is not likely to lower electricity tariff. Rather it is likely to raise tariff.

Narrative 3: Biophysical constraints

Biophysical constraints on economic growth in general and on energy use in particular has been under discussion at the global level and also in India for a long time. One influential work on this topic was the report titled 'The limits to growth' by the Club of Rome published in 1972. It is an acknowledgement of the fact that production takes place only with some use of natural resources including energy. Energy is more important for production than either capital or labour[18]. This has given rise to the field of Biophysical Economics which acknowledges that transformation of inputs into outputs needs energy and natural resources, and any process that needs energy is subject to laws of thermodynamics. Traditional economists believe that any resource scarcity or degradation of earth systems can be remedied by technological advances, but biophysical economists opine that one might reach non-reversible tipping points if issues of resource scarcity and degradation are not addressed well in time[18].

With regard to energy resources, one important characteristic is net energy gain to society. In nineteen seventies, this was expressed in terms of life cycle assessment of energy flows, and now it is expressed in terms of the ratio 'Energy Returned Over Invested' and abbreviated as EROI. To get energy from any resource, say petroleum or coal, one has to invest energy to extract the resource, to process or convert it before use, and to transport or transmit it to the consumer. Energy for Society or Energy Gain is the difference between the output and input energy and one can see the importance of EROI by looking at Figure 2, first plotted by Mearns[19]. Points on this curve are based on the solution of the following equations.

$$E_{out} = 100,$$

$$\text{Energy gain} = E_{out} - E_{in},$$

$$\text{EROI} = E_{out}/E_{in}.$$

The curve derives its name 'Energy Cliff' from the steep fall in energy for society as EROI falls below about 6. A low EROI implies that the size of the 'energy enterprise' that is requirement of energy resources, manpower, materials, land, etc. is very large and so is the effect on environment. EROI calculations are done using life cycle energy flows as energy is needed directly as well as indirectly : directly at the mine or oil well and indirectly for manufacturing equipment and components for setting up plants, for transportation or transmission including setting up needed infrastructure, and also for eventual disposal of decommissioned plants. There is a divergence in EROI estimates by different researchers due to methodological issues. Issues involved are consistency of system boundary for analysis, convention followed for addition of energy inputs from different sources such as hydro,

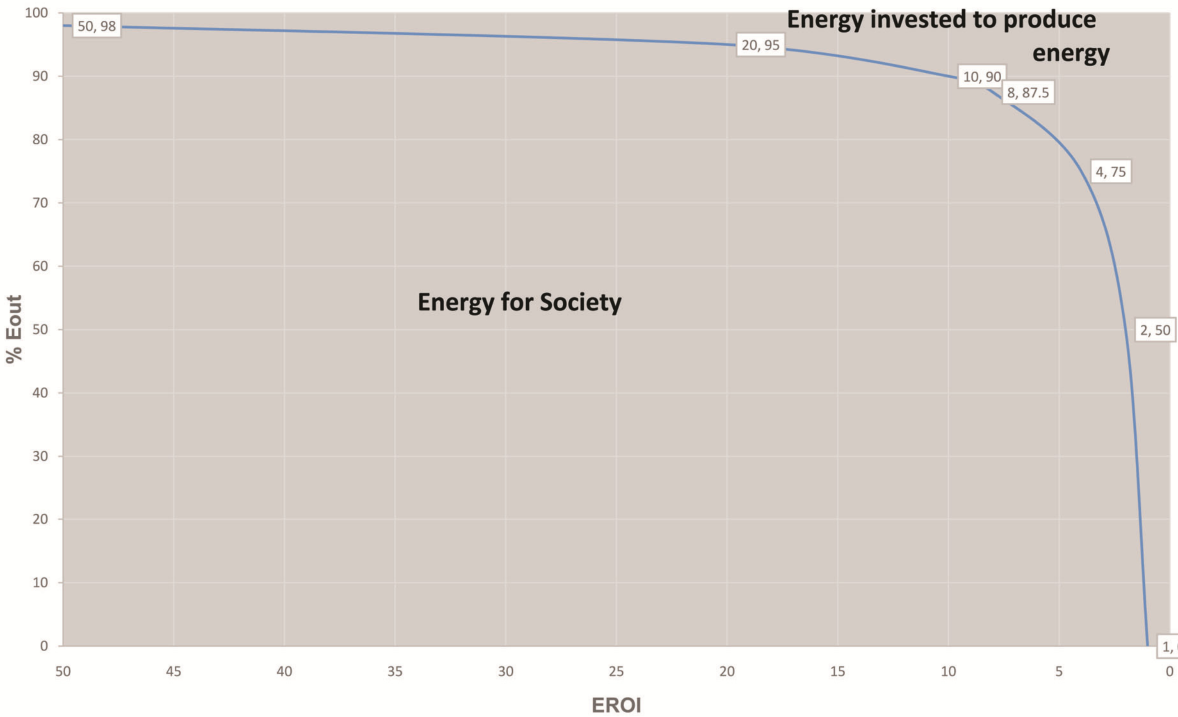

Figure 2. Energy cliff.

nuclear and coal, difference between the EROI of the source and EROI of the energy supply system of the society calculated on the basis of TFC, accounting of energy invested in supply chain, treatment of energy invested in imported resource or equipment etc. In case of RES, accounting for EROI of storage solutions to address intermittency is an additional issue.

Recent publications[20–22] address these issues appropriately and may be seen for details. Neumeyer and Goldston[20] have calculated both static and dynamic EROI. Dynamic EROI captures the dynamics during rapidly changing energy transition as energy investment is needed to set up a new generator. Irrespective of differences in details, there is agreement, that technologies like fossil fuels, large hydro, nuclear and wind have high EROI, while solar is about the point where steep fall begins. When combined with storage, EROI of solar falls further. Because of large energy spent in collection of the fuel, bio-fuels have very low EROI. Units with low EROI, provided they have some positive externality can be planned to co-exist with units having high EROI. Example can be a power plant designed to produce electricity using stubble as a fuel thereby eliminating pollution caused by burning stubble in fields. Estimates also indicate that with the depletion of resources, EROI of fossil fuels, particularly oil and RES would become comparable[21].

Until the industry starts accounting for externalities, EROI will not directly manifest in energy cost, but is an important tool for energy planners to analyse the electricity mix of a country. One can think in terms of EROI of an individual source or in terms of the nation as a whole. Estimates have been made even for global EROI with a view to understand its influence on global economy[21]. This is an emerging area of research, but some opinions have already been articulated. Lambert *et al.*[23] estimate that for a society having EROI less than 15 to 25, quality of life is likely to be poor. A higher standard of living can be expected only when EROI is above 20 to 30. The authors have devised a 'pyramid of energetic needs' similar to Maslow's pyramid of human needs. At low EROI, energy for discretionary spending is not available. This is also stated by Brandt[24], and his list of discretionary activities includes advanced education, science, entertainment, temperature controlled spaces and discretionary travel. Minimum EROI is closely related to energy intensity of an economy, and for the US economy, Fizaine and Court[25] state that it requires a primary energy system with a minimum EROI of 11 to enjoy a positive rate of growth.

As fossil fuels become scarce, their EROI is declining, and that has implications for long-term economic growth. As oil industry starts exploiting more and more unconventional oil, it will accelerate resource acquisition rate, and therefore degradation of natural environment[26].

The above examination of narrative 3 points that there is a need to launch an India-specific study to estimate EROI of the Indian economy and use insights gained to plan further evolution of the electricity mix in India.

Another often mentioned biophysical constraint is the use of scarce materials in various generation technologies. At this stage, there is no concrete evidence regarding it becoming a limitation for growth of any of the generating options.

Narrative 4: Phasing out of coal

In view of carbon emissions, and significant health externalities[27] arising from the effect of plant emissions on exposed populations, many advocate a complete phase-out of coal-fired power plants. However, coal is a dominant part of the present electricity generation mix in India and contemplating its phase-out needs a very careful study and in my opinion a complete phase-out is not desirable as it would reduce diversity of the electricity mix. Continued use of coal is also desirable to ensure that the energy supply system of the country has a high enough EROI. For this I would endorse the approach based on stabilization wedges for climate control first proposed by Socolow and Pacala[28], who advocate a combination of initiatives including efficiency improvements in electricity generation from coal-fired power plants, carbon capture and storage, increasing generation from nuclear, solar, wind, bio-mass, end-user efficiency improvement and conservation. India should plan to taper down percentage contribution from coal-fired power plants to a certain minimum over the next three to four decades. All new coal fired plant should be designed to have high thermal efficiency and be equipped with pollution abatement equipment.

With regard to efficiency improvements in generation from coal, the Government has already taken up a Research and Development (R&D) project for the development of Advanced Ultra Supercritical technology for thermal power plants. R&D phase is ongoing and proposed to be followed by setting up a demonstration plant of 800 MW rating having a thermal efficiency of 46%. The demonstration plant would also incorporate pollution abatement technologies to minimize particulate emissions, and also emissions of SO_2 and NO_x. The R&D project is being implemented by a consortium of NTPC, BHEL and IGCAR. A demonstration plant is planned to be built by NTPC at Sipat in Jharkhand.

The Government of India is also working to minimize pollution from existing coal-fired plants. Vide its notification in 2015, the Ministry of Environment, Forests and Climate Change has already modified its norms for emission of suspended particulate matter and introduced new norms for emission of SO_2, NO_x and mercury from thermal power plants. The notification provided a two-year window from the date of notification for implementation, but the window was later extended to 2022. The progress in implementation is slow essentially due to cost and financing issues[29]. As a way forward, Kanitkar *et al.*[30] have suggested progressive retirement of sub-500 MW plants that are older than 25 years by 2022 instead of retrofitting them with expensive Flue Gas Desulphurizers (FGDs). This would lead to better utilization of newer and cleaner thermal plants and also limit the increase in tariff that would result from the FGD retrofitting.

The above examination of narrative 4 indicates that a complete phase-out of coal-fired power plants is not possible in view of their large contribution to the electricity mix and to maintain diversity in the mix. Steps to develop high efficiency coal-fired plants and retrofit pollution abatement equipment in existing plants are appropriate initiatives and should be earnestly pursued.

Narrative 5: Safety issues

Safety issues associated with nuclear power generation have come to dominate public discourse because of three accidents namely Three Mile Island (1979), Chernobyl (1986) and Fukushima (2011). With regard to consequences of these accidents, there are different viewpoints. Rather than viewpoints, let us examine data.

Data on death rates from air pollution and accidents has been collected by researchers and contrary to popular belief, nuclear is by far safer than fossil fuels, and modern renewables are as safe as nuclear energy[31]. To arrive at this conclusion, Ritchie combines data from two published sources, Markendaya and Wilkinson[27], and Sovacool *et al.*[32]. Data on health externalities from various technology options is based on studies done in Europe where dose-response function will be different from that in India because of different climatic as well socio-economic conditions. There is a need to generate such data in India.

Regarding nuclear waste management, pursuit of a closed fuel cycle with minor actinide separation provides a superior alternative and that is what India has been pursuing. Pursuit of a closed fuel cycle reduces high-level radioactive waste per unit of electricity produced and minor actinide separation reduces the duration for which nuclear waste has to be stored[33].

India has made good progress with regard to developing nuclear technologies on a broad front as summarized by Grover and Srinivasan[34]. With uranium now being available from international market, and given the large number of reactors now under construction and also approved for construction, share of nuclear in electricity generation is set to rise in coming years. Despite data favouring nuclear safety and pursuit of a closed fuel cycle by India, a section of the public continues to be apprehensive about nuclear safety. This is partly due to the fact that a nuclear accident is perceived to be a ‘low-probability, high-consequence (LPHC)’ event and all such events leave a lasting impression on human psyche. LPHC events can be minimized, and post-accident emergency managed only by establishing best practices at the global level. This is precisely what has been done by the nuclear industry. Two initiatives deserve mention here; one is the Nuclear Safety Convention and the other is the establishment of World Association of Nuclear Operators. India is a party to both the initiatives. Still to allay apprehensions of the public, nuclear industry has been engaging with public and needs to further strengthen this engagement.

The above examination of narrative 5 tells us about the need for the nuclear industry to further improve engagement with the public to convince them about the safety of nuclear energy. Also there is need to conduct studies in India to collect data regarding health externalities of different technologies of electricity generation.

Concluding remarks

Examination of various narratives leads us to make the following observations to inform public and nudge policies.

- Electricity demand in India has been growing and will continue to grow for coming several decades. Any short-term sluggishness in demand is not a pointer to long-term slow down.
- RES (based on present technologies) and large hydro cannot meet the projected electricity demand.
- Continued use of LCOE as a metric to evaluate technology options is erroneous and will lead to wrong conclusions. As LCOE is embedded deep in the practices followed by the industry, a concerted effort is needed to make decision makers aware about its shortcomings when comparing intermittent and despatchable technology options.
- Experience of other countries indicates that integration of RES to the grid is likely to raise tariff for consumers.
- EROI is an important parameter and needs to be studied in detail for planning energy supply system of the country.
- A phase-out of coal-fired power plants is not desirable as it will lower EROI of the energy supply system, and reduce diversity of the electricity mix. Rather efforts should be made to ensure that plants to be constructed in future have a higher thermal efficiency and are equipped with pollution abatement equipment.
- Risks are associated with all technologies, though there are differences. It is necessary to have a continuous dialogue with public on this subject with the objective of providing them with scientific information and continually work to allay their apprehension.

Given India's energy resources, the electricity mix has to include solar, wind, hydro and nuclear to meet the imperative of decarbonization. Until generation based on these resources can be ramped up to meet the demand, coal has to continue to be a part of the electricity mix. Need to keep the electricity generation mix diverse and keep EROI high would require continuation of coal for ever.

In addition to development of technologies, research agenda has also to include issues related to energy economics and health externality of various technology options. The objective has to be to arrive at an electricity generation mix that (i) is acceptable from climate change perspective, (ii) has enough built-in diversity to provide security of supply and resilience against unforeseen events, (iii) gives an EROI to the energy supply system of the society calculated on the basis of TFC which can be considered optimum for the economic growth of the country, and (iv) results in acceptable tariff for the consumer. Diversity directs one to look at the positives of all sources and not to neglect any source. System analysis should be used for correct attribution of grid-level cost. Not doing so implies subsidizing some technologies without even knowing which one are being subsidized and to what extent.

1. Energy Statistics – 2020, Ministry of Statistics and Programme Implementation, Government of India.
2. India 2020: Energy Policy Review, International Energy Agency.
3. Power sector at a glance, Ministry of Power; https://powermin.nic.in/en/content/power-sector-glance-all-india (accessed on 24 April 2020).
4. Ali, S., *The Future of Indian Electricity Demand: How Much, by Whom, and Under What Conditions*? Brookings India, October 2018.
5. Energy, electricity and nuclear power estimates for the period up to 2050, IAEA reference data series no 1, August 2019 edition.
6. Energy, electricity and nuclear power estimates for the period up to 2050, IAEA reference data series no 1, August 2016 edition.
7. Annual Report 2019–2020, Ministry of New and Renewable Energy.
8. Jacobson, M. Z. and Delucchi, M. A., Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and are as of infrastructure, and materials. *Energy Policy*, 2011, **39**, 1154–1169.
9. Delucchi, M. A. and Jacobson, M. Z., Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies. *Energy Policy*, 2011, **39**, 1170–1190.
10. Sukhatme, S. P., Can India's future needs of electricity be met by renewable energy sources? A revised assessment. *Curr. Sci.*, 2012, **103**(10), 1153–1161.
11. Statista, Penetration rate of refrigerator market in India from 2005 to 2026; https://www.statista.com/statistics/857117/india-refrigerator-market-penetration-rate/ (accessed on 10 May 2020).
12. TechSci Report, India UPS market; https://www.techsciresearch.com/report/india-ups-market/1502.html (accessed on 8 May 2020).
13. Ueckerdt, F., Hirth, L., Luderer, G. and Edenhofer, O., System LCOE: What are the costs of variable renewables? *Energy*, 2013, **63**(issue C), 61–75.
14. Graham, P., Review of alternative methods for extending LCOE to include balancing costs, CSIRO, Australia, 2018.
15. Nuclear Energy Agency, The full costs of electricity provisions, NEA No. 7298, 2018.

16. Orr, I., If renewables are so cheap why is Germany's electricity so expensive? November 2018; https://www.americanexperiment.org/2018/11/renewables-cheap-germanys-electricity-expensive/ (accessed on 13 May 2020).
17. Scroggin-Wicker, T. and McInerney, K., Flow batteries: Energy storage option for a variety of uses, Power, March 2020; https://www.powermag.com/flow-batteries-energy-storage-option-for-a-variety-of-uses/ (accessed on 8 May 2020)
18. Hall, C. A. S. and Klitgaard, K., *Energy and Wealth of Nations: An Introduction to Biophysical Economics*, Springer Nature, 2018.
19. Mearns, E., The global energy crisis and its role in the pending collapse of the global economy. Presentation to the Royal Society of Chemists, Aberdeen, Scotland, 29 October 2008.
20. Neumeyer, C. and Goldston, R., Dynamic EROI assessment of the IPCC 21st century electricity production scenario. *Sustainability*, 2016, **8**(5), 421; doi:10.3390/su8050421.
21. Brockway, P. E., Owen, A., Brand-Correa, L. and Hardt, L., Estimation of global final-stage energy-return-on-investment for fossil fuels with comparison to renewable energy sources. *Nature Energy*, 2019, **4**(7), 612–621.
22. King, L. C. and van den Bergh, J., Implications of net energy-return-on-investment for a low-carbon energy transition. *Nature Energy*, 2018, **3**, 334–340.
23. Lambert, J. G., Hall, C. A. S., Balogh, S., Gupta, A. and Arnold, M., Energy, EROI and quality of life. *Energy Policy*, 2014, **64**, 153–167.
24. Brandt, A. R., How does energy resource depletion affect prosperity? Mathematics of a minimum energy return on investment (EROI). *Biophys. Econ. Resour. Quality*, 2017, 2.2; doi:10.1007/s41247-017-0019-y.
25. Fizaine, F. and Court, V., Energy expenditure, economic growth and the minimum EROI of society. *Energy Policy*, 2016, **95**, 172–186.
26. Murphy, D. J., The implications of the declining energy return on investment of oil production. *Philos. Trans. R. Soc.*, 2014, **A372**, 20130126.
27. Markandeya, A. and Wilkinson, P., Electricity generation and health. *Lancet*, 2007, **370**, 979–990.
28. Socolow, R. H. and Pacala, S. W., A plan to keep carbon in check. *Sci. Am.*, 2006, 50–57.
29. Emissions control in thermal power stations: issues, challenges, and the way forward, Discussion paper, The Energy and Resources Institute, January 2020.
30. Kanitkar, T., Thejesh, N., Ranjan, U. and Srikanth, R., Optimal electricity mix for the southern region, summary report of NIAS–MOES Workshop, 17 January 2020.
31. Ritchie, H., *What are the Safest Sources of Energy*? https://ourworldindata.org/safest-sources-of-energy (accessed on 15 July 2020).
32. Sovacool, B. K. *et al.*, Balancing safety with sustainability: assessing the risk of accidents for modern low-carbon energy systems. *J. Cleaner Prod.*, 2016, **112**, 3952–3965.
33. Wattal, P. K., Back end of Indian nuclear fuel cycle – A road to sustainability. *Prog. Nucl. Energy*, 2017, **101**, 133–145.
34. Grover, R. B. and Srinivasan, M. R., Vikram Sarabhai: his vision for the development of atomic energy in India. *Curr. Sci.*, 2020, **118**(8), 1191–1195.
35. Key World Energy Statistics, International Energy Agency, 2018.
36. Human development Indices and Indicators, Statistical Update, United Nations Development Programme, 2018.

ACKNOWLEDGEMENT. I thank S. C. Chetal for a discussion on Advanced Ultra Supercritical technology.

Received 19 July 2020; accepted 13 December 2020

doi: 10.18520/cs/v119/i12/1910-1918