Estimating minimum energy requirement

Comments on the article 'Estimating minimum energy requirement for transitioning to a net-zero, developed India in 2070', published in *Current Science* (2022, **122**(5), 517–527). Some material is also added from IEA Net Zero by 2050, and World Energy Outlook 2021 prepared from COP 26.

Authors (R. Bhattacharyya *et al.*) must be congratulated for bringing out a comprehensive energy policy document after reviewing many previous studies.

While an HDI of 0.9 is a good target, 0.8 would be more realistic. Most of the studies quoted by the authors in Appendix I take a value of 0.8. The average value of India is about 0.68, but many large states have deficit HDI values.

HDI of 0.8 ensures a good standard of living, including shelter, clean water and food, good mobility, entertainment like television and internet and comfortable living conditions at home.

While little doubt exists about the electricity/energy/HDI correlation, wide variations exist. In India, Kerala has an HDI of 0.8 with a per capita electricity consumption of 757 kWh/annum. Gujarat, with 2378 kWh/capita/annum, has an HDI of 0.68, the same as the average value for India.

The 16,000 kWh/capita/annum suggested by the authors seems quite high and will face resource, sustainability and technology problems.

The authors and Net Zero by 2050 and World Energy Outlook 2021 emphasize electrification because solar and wind can only produce electricity easily. For modern 24×7 requirements of electricity, solar and wind cannot do this job without a storage medium. Battery storage at over 100$/kWh or kW is costly and requires scarce materials.

As the author suggested, using hydrogen as a carrier, fuel and storage medium will face many technical problems and safety issues. This is also true for carbon capture and storage. Carbon capture and storage have been talked about for a long time but have not made much progress.

Operation of stable grid with such large variable sources is not possible without good storage. Natural gas and hydro only can do this job. Batteries remain unviable for large storage.

We must explore the following:

As suggested by the authors, priority must be given to energy efficiency. While BEE and PCRA are doing a good job, they have few people and financial resources. They must be given much larger resources. The programme of LED bulb has been an outstanding success. Such programmes must be introduced for other equipment and subsidized, if necessary.

Public transport must be given high priority.

High priority must be given railway network development. The railway network today covers 60,000 km. Railways used to carry 70–80% of freight and passenger traffic, the remaining 20–30% is carried by road. The ratios are reversed now. This has led to a huge surge in oil demand. All studies expect oil dependence to be 80–90% in the foreseeable future. Electrification of road transport remains needs to be done. To curb oil demand due to the war in Ukraine, the IEA has suggested overnight trains instead of planes.

For cooking, the authors suggest induction cooking. This does not look feasible. Both Net Zero by 2050 and World Energy Outlook suggest a significant role of bioenergy. Renewable and nuclear energy are other sources.

In India, agricultural waste and cow dung are available, and they are renewable resources. They must be used for cooking with improved chullas and solar cookers. This is a sustainable solution. LPG and electrical cooking depend on non-renewable sources. IEA also emphasizes the role of modern bioenergy.

As per World Energy Outlook 2021 for COP 26, final consumption is 343 EJ. Out of this 169.2 EJ is electricity. Liquid fuels contribute 65.8 EJ. Solid fuel contribute 38.7 EJ. In solid fuel significant contribution is from modern biofuels.

While the authors do not specifically mention emission control, both Net Zero by 2050 and World Energy Outlook 21 depend on capturing emissions from the air and using modern bioenergy. Emissions do not become zero. They are captured.

A target of 30–35 GJ with 60–65% contribution from renewable electricity, 10–15% from biomass, and the rest from conventional liquid fuels and gas will be reasonable to achieve an HDI of 0.8.

Conventional fuel, especially oil, will continue to be used for transport. Natural gas for grid stability, transport and cooking applications.

Net Zero will have emissions but captured and mitigated. Technical breakthroughs are required in biofuel, energy storage and CO_2 capture.

I would also like to draw attention to Goal 12 of the 'Sustainable Development Goals' of the United Nations. This goal emphasizes responsible consumption and production. It is time for all concerned with policy to start working on this goal. There is little logic in promoting private transport and short-distance air travel. COVID has shown work from home, and virtual conferences are viable solutions. They need to be followed even in normal times.

Again, I congratulate the authors for producing such a monumental study, usually done by IEA, Niti Ayog or CEA.

B. G. DESAI

Community Science Centre,
Aarti Society,
Atmjyoti Ashram Road, Subhanpura,
Vadodara 390 023, India
e-mail: cscvadodara@yahoo.co.in

Response:

We thank B. G. Desai for the appreciation and interest shown in our work and for the detailed comments provided on it. In performing this study, we have considered a nearly 50-year time frame in setting a target for the HDI. We firmly believe that India should aspire to provide not just a minimum decent quality of life but a high standard of life that is currently enjoyed by the citizens of the most developed economies today, many of whom have HDI exceeding 0.9. We agree that several nations with HDI of about 0.8 do indeed provide a reasonable standard of living to their citizens, but our aspirations and ambition for the India of 2070 (123 years after Independence) are greater than that, and that is reflected in our choice of the target HDI.

We agree that state-wise HDI values vary greatly depending on socio-economic factors, not just energy consumption within the boundaries of the state. For Kerala, HDI is high owing to higher literacy levels and larger foreign remittances from residents working abroad/NRIs. In addition, manufacturing activity has no significant presence in Kerala and purchases all manufactured products from other Indian states.

Gujarat is a highly industrialized state, which explains its higher per capita energy consumption. Thus, one needs to consider the 'energy footprint', which includes economic and wealth-generating activities carried outside the geographical boundaries of a state or region (which in turn consumes energy elsewhere) but directly contributes to the welfare of that state. We use the average HDI value for India to suggest a target energy consumption value for the entire country as a means to support decision-making at the central level, but we do not suggest that the same programme should be implemented or the same pace of growth can be attained everywhere at the same time. State-specific strategies are needed when planning the energy infrastructure to be deployed to attain that target.

We do not agree that the target energy generation of 16,000 kWh/capita/annum is very high; in fact, it is commensurate with the assumptions made in this study[1] and scenarios suggested for India for strictly achieving Net-Zero in all sectors of the economy. This is not just direct consumption of electricity by an individual (which today is about 18% of total final energy consumption) but also includes electricity required to generate new energy vectors such as hydrogen and to support energy-intensive measures like carbon capture, all of which would be required in our transition to a Net-Zero India that meets its Paris Agreement Commitments[2] and the more stringent programmes announced at COP 26, Glasgow, November 2021. The number can be lower (but not as low as previous estimates of 5000 or 8000 kWh/capita/year), if breakthroughs are achieved in energy conversion technologies and energy efficiencies, but there will be thermodynamic limits on these factors and experience from the developed nations shows that these limits are fast being approached. Also, energy efficiency and conservation efforts must not be limited to domestic gadgets and appliances running on electricity; they must extend to industrial installations.

It is not an easy target to meet and will require fundamental shifts in the energy planning and provision processes. Previous studies did not consider the need for achieving Net-Zero alongside high levels of human welfare; they also assumed low elasticity of energy demand concerning growth which does not reflect India's historical or present reality. That is why those estimates are rather low compared with what has been presented in this work; those estimates should not become the basis for long-term planning. In meeting this target, we do not suggest anywhere that wind and solar PV alone will enable all sectors to be electrified and for all sectors to reach net-zero emissions precisely because of their variability, intermittence and the need for expensive battery storage. Base load generators of clean thermal energy and electricity, such as nuclear power (both large centralized power plants and smaller modular variants with advanced design, safety features and construction), will be required to economically and reliably provide energy to various consumers in various settings.

While we fully agree that the energy transition will involve many technical, economic and social challenges, there should be no reluctance to address and resolve them. Certain sectors, most notably those that already use fossil fuel-derived hydrogen today (e.g. ammonia production for the fertilizer industry), cannot be decarbonized unless low-carbon hydrogen is produced and used to substitute carbon-intensive sources. And technology upgrades and major changes will be also required in other sectors; the clean energy transition alone will not bring about decarbonization everywhere, such as in cement, where emissions arise from process chemistry. Carbon capture will be inevitable there. We consider carbon capture in specific energy planning scenarios where we have not entirely done away with the use of fossil fuels, and we include the associated energy penalty with the deployment of such technology while calculating the energy targets. We consider these technologies to be deployed only when energy or raw material use produces concentrated streams containing CO_2, such as in thermal power plants, cement factories and petroleum refineries. We firmly believe the best alternative is to reduce and stop combustion-related emissions altogether rather than continue using them with post-combustion emissions management. Direct air capture is necessary, but the technology-mediated pathways are difficult and expensive. CO_2 removal from the air is best managed by natural means, including forestry, ocean-based capture by ocean vegetation restoration, carbon stock incorporation in soils, etc. Nature-based means of climate change mitigation and adaptation provide numerous co-benefits as well.

We do not advocate perpetuating the use of natural gas in India, mainly because more than 60% of natural gas used here today is imported. Methane emissions are a far more potent global warming agent, which would rise if natural gas use rises. Placing too much dependence on fossil fuels and creating new fossil-dependent infrastructure (e.g. blue hydrogen production) while targeting net zero is not prudent. Hydel power is certainly a better option, but there are geographical constraints on siting such plants, not to mention that they are very susceptible to climate change and seasonality of water availability and their construction leads to large environmental and socio-economic footprint.

Regarding transport sector decarbonization and reducing fuel requirement therein, improving public transport networks and changing the mindset of people (for many of whom owning private vehicles may have socio-cultural connotations rather than an urgent need) are required simultaneously. Eighty per cent of the railways are already electrified, but until and unless the electricity used to run trains or any other form of transport is clean, further electrification will not solve the problem of greenhouse gas emissions, though it does help with reducing local emissions. Railways can also support mixed-mode transport, such as roll-on and roll-off arrangements for freight trucks that reduce the need for battery-charging infrastructure.

With respect to biomass-based energy, the bio-energy used today in India (particularly rural India), its unprocessed form (e.g. agriculture or forestry residue) causes significant indoor air pollution (with health impacts disproportionately borne by women and children), not to mention carbon emissions. Processing biomass into cleaner-burning forms such as bio-gas and bio-ethanol are themselves highly energy inefficient processes, often producing very low or even negative returns on energy invested in such technology when considering the entire life cycle (values between 0.68 and 3.12 have been reported, as indicated in the paper). Their use is often supported as drop-in substitutes for fossil fuels in the transport sector, but there is also no assurance that their use will be sustainable or carbon neutral overall. Land and water use conflict is a real danger when trying to grow massive amounts of energy crops alongside food crops and other cash crops. Therefore, we have considered these as secondary energy or material resources and have exercised caution in relying too much on their application. However, in cases where positive externalities accompany the use of biomass, it should be considered.

We also fully agree that it is not only a question of large-scale, institutional means to be implemented for energy transition and human welfare; individual action and massive shifts in behavioural patterns at all levels are required too. For example, while private organizations have continued supporting remote work, the public sector must adapt to the new reality and adopt this behaviour everywhere possible.

Overall, the estimate of 30–35 GJ is too low, in our opinion. And as the most recent data in figure 3 *b* of the paper[1] shows, no country today has achieved an HDI of even 0.8 with this level of energy consumption per capita per annum. A value of about 50 GJ/capita/year would still be required even if we continue with our business-as-usual patterns of production and consumption. Vogel's[3] estimates this number to be as high as 60 GJ/capita/year. One must carefully choose the technologies to lead us to net-zero, and that too at a rapid pace. India's nuclear power programme is largely indigenous and poised for major growth this decade; this and renewables must be leveraged optimally. One must not ignore deployment ready technologies while banking too much on alternatives that are not yet technically or commercially mature.

1. Bhattacharyya, R., Singh, K. K., Grover, R. B. and Bhanja, K., *Curr. Sci.*, 2022, **122**(5), 517–527.
2. MoEF, India's INDCs, 2015; https://moef.gov.in/wp-content/uploads/2017/08/INDIA-INDC-TO-UNFCCC.pdf (last accessed on 15 December 2021).
3. Vogel, J., Steinberger, J. K., O'Neill, D. W., Lamb, W. F. and Krishnakumar, J., *Global Environ. Change*, 2021, **69**, 102287.

RUPSHA BHATTACHARYYA[1,2,*]
K. K. SINGH[1,2]
R. B. GROVER[1]
K. BHANJA[2]

[1]*Applied Systems Analysis,*
Homi Bhabha National Institute,
Mumbai 400 094, India
[2]*Chemical Engineering Group,*
Bhabha Atomic Research Centre,
Mumbai 400 085, India
**e-mail: rupsha@barc.gov.in*