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The indian energy and emission outlook: A case for solar energy

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Abstract

In line with India's aims to get Viksit Bharat status by the year 2047, India has to grow much faster than it has so far. Such a high rate of growth will invariably lead to more energy consumption & more emissions, necessitating large scale renewable energy interventions. In spite of multifarious policy interventions and technological/financial improvements in renewable energy front over the last 2 decades, fossil fuel still dominates the energy scene, resulting in an ever-increasing trend of emissions worldwide. In India, though at a per capita level, emissions are very low, at a gross level, the emissions are growing at a little uncomfortable pace. The third world's argument for the right to emit more was accepted at the worldwide multi-lateral level, leading to the carbon-market mechanisms enshrined under the 'Kyoto Protocol'. However, after the end of the 'Kyoto Protocol' commitment period (2008-2012), the focus has shifted to 'overall emissions', where India is as big a responsible State as the likes of USA. Therefore, the shift to renewables for India has been of as paramount importance as any other developed or developing nation. Amongst the modern renewable energy options, the scope & scale of energy from wind/geothermal/small hydro/biomass/etc. sources appear limited due to their inherent drawbacks viz. higher upfront costs, high-maintenance, modularity & scalability. In contrast, solar energy has multifarious advantages viz. anywhere-installation-option, modularity & scalability, off-grid-option, etc. Moreover, solar-at-scale can help create an ecosystem for manufacturing & job creation and also help India move towards its Net Zero target.

Introduction

Modern society relies heavily on energy to power its houses, businesses, transportation, and technology. However, the ecosystem and the planet's climatic systems are greatly impacted by the production and consumption of energy. Fossil fuels including coal, oil, and natural gas have dominated the energy landscape for centuries. Burning these fossil fuels emit a lot of greenhouse gases (GHGs) into the atmosphere, including methane (CH_4) and carbon dioxide (CO_2). Rising temperatures, harsh weather, and ecological upheaval are all consequences of these emissions, which are a major contributor to global warming. To solve the environmental

problems caused by our insatiable urge to burn fossil fuels, the world is moving towards renewable energy (RE) options viz. wind, solar, geothermal, hydro, biomass etc. Each of these choices has special advantages and they help to lower greenhouse gas emissions, decrease air/ water pollution, and promote energy security.

During the last few decades, solar and wind energy have seen tremendous technological and financial breakthroughs, making them more widely available to people, companies, and governments. Societies may balance economic progress with environmental stewardship and strive towards a cleaner, healthier, and more resilient future by investing in and implementing renewable energy systems. In addition to being a necessity for the environment, this shift offers the global energy industry a chance to spur innovation and generate green jobs.

India Aims to be US$ 30 Trillion Economy by 2047

As per the report of International Monetary Fund (World Economic Outlook, 2004)[i], for the year 2024-25, India's GDP is expected to grow at 6.8%, which is much more reassuring vs. China (4.6%), USA (2.7%) and the World (3.2%).

India is already a US$ 3.5 trillion-dollar economy[ii] (Nominal GDP, World Bank-World Dvpt. Indicators, 2023) and Govt. of India has set impressive targets to reach Gross Domestic Product (GDP) of US$ 5 trillion in next 2 years (i.e., by 2027), US$ 7 trillion in next 5 years[iii] (i.e., by 2030) (Min. of Finance Govt of India, 2024) and US$ 30 trillion by 2047[iv] (i.e., in the hundredth year of India's independence) (Press Information Bureau Govt of India, 2024).

To take the size of economy from US$ 3.5 trillion to US$ 30 trillion in 2047 (i.e., in 25 years), the corresponding CAGR would be 8.9%, which appears reasonable at present, considering the last 3 years' actual GDP (Constant 2015 US$) growth rates of 9.7% (2021), 7% (2022) and 7.6% (2023)[ii] (World Bank-World Dvpt. Indicators, 2023).

The Indian government's think tank, Niti Aayog, is already working on a master plan to reach GDP of US$ 30 trillion by 2047, with per capita income reaching the range of US$ 18,000 to US$ 20,000, which is 7.5x of the current per capita GDP (Nom, 2023) of US$ 2485/head[v] (World Bank-World Dvpt. Indicators, 2023). As per Niti Aayog, to reach the GDP of US$ 30 trillion by the year 2047, India will have to create an enabling environment to multiply its exports to US$ 8.67 trillion by 2047[vi] (LRRDIS Parliament Ref. Note Govt of India, 2023), i.e., multiple of about 20x from the existing exports of US$ 437 billion (2023-24)[vii] (DGFT Ministry of Commerce & Industry Govt of India, 2024). In addition to achieving the goal of export-led economy, Niti Aayog is also working out action plan towards large scale macro-economic interventions with thrust on manufacturing/high-tech capex, digital economy, value-added agriculture, liberalization & ease of doing business, etc. to achieve *Viksit Bharat* status by 2047.

Role of Energy Sector - Pivotal to Achieve *Viksit Bharat* Status by 2047

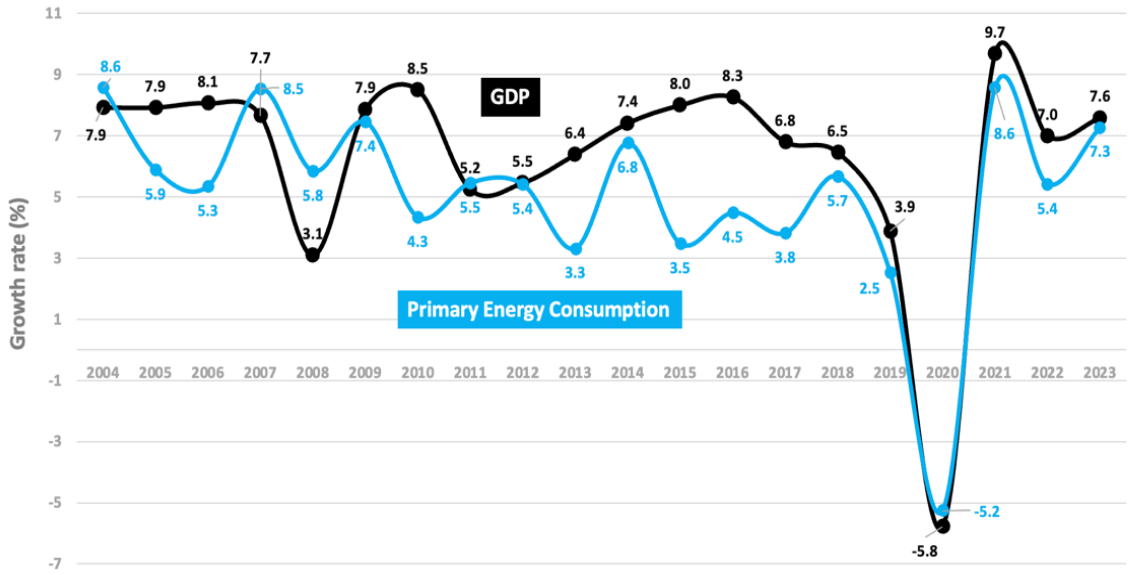
Energy is the key underpinning of any modern/industrial economy, be it for transportation, cooking, lighting, water/space heating, food production and storage, mineral extraction,

industrial production, etc. It is, therefore, generally accepted that economic growth of a country pre-supposes commensurate growth in energy consumption. In order to aid & sustain a high-growth economy like that of India, energy sector, therefore, will play a pivotal role.

If one plots India's year-to-year growth rates of GDP (Constant 2015 US$) vs. Primary Energy Consumption for the last two decades, one can see a more-or-less correlative trend between the two variables (***Figure 1***). The question, which is often deliberated in the research/academia circles is, whether energy production/consumption drives GDP growth or vice versa? (Grażyna Szustak et al., 2021)[viii]. While researching to find out such co-relationship for many countries, it was concluded that the relationship is random (Namit Sharma et al., 2019)[ix]. But it is also fact that, as a country's GDP increases especially in the developing countries, so does its economic prosperity, leading to more disposable income in the hands of the general populace, thereby increasing the need to meet personal aspirational goals, resulting in higher energy consumption. If one compares the size of GDP of the largest economies against their world ranking of their energy consumption, one can see a more or less distinct trend, i.e., typically, the largest economies are the largest consumers of primary energy (***Figure 2***).

So, availability of various energy options & efficient energy services is essential for social & economic transformation. All countries in the world, who have grown reasonably well during the last century, have done it, thanks to the availability and accessibility of affordable energy options for a large section of their citizens.

Figure 1: India's y-to-y growth rate (%): GDP (constant 2015 US$) vs. Primary Energy Consumption
Period: Last 2 decades (2004 to 2023)



Analysis and Chart by the Author, based on data from Energy Institute (2024) & World Bank Development Indicators Dataset 2024

Figure 2: World ranking: GDP vs Energy Consumption
Year: 2023

Country	2023 GDP (Constant 2015 US$)		Primary Energy Consumption, 2023	
	US$ trillion	World Rank	Exa Joules	World Rank
USA	21.8	1	94.3	2
China	17.2	2	170.7	1
Japan	4.6	3	17.4	5
India	3.2	4	39.0	3
France	2.7	5	8.7	13
Italy	2.0	6	5.9	18
Brazil	2.0	7	13.9	7
Canada	1.8	8	13.9	6
Korea, Rep.	1.8	9	12.4	9
Australia	1.6	10	6.0	17

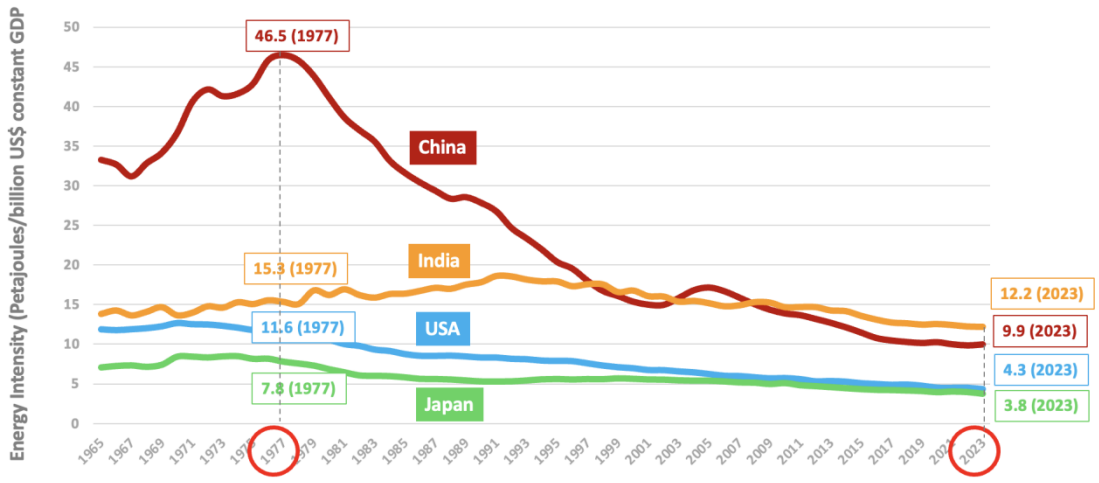
Analysis and Chart by the Author, based on data sourced from Energy Institute (2024) & World Bank Development Indicators Dataset (2024)

High Energy Intensity of India's GDP

India, with 2023 energy consumption of 39 exajoules[x] (Energy Institute, 2024)[xi], is the world's third largest energy consumer [behind China (171 exajoules) & USA (94 exajoules)]. At 2023 GDP of US$ 3.2 trillion (Constant, 2015 US$), India is the 4th largest economy of the world [behind USA (US$ 22 trillion), China (US$ 17 trillion) & Japan (US$ 4.6 trillion)]. Interestingly, while India's share of the world's GDP is only 3.4%[xii] (World Bank-World Dvpt. Indicators, 2023), its share of world's energy consumption is 7.3% (Energy Institute, 2024), signifying very high energy intensity of India's GDP, e.g., during 2023, while India consumed 12.2 petajoules[xiii] of energy for generating every billion $ of its GDP (Constant 2015 US$), the same for China, USA, & Japan were 9.9, 4.3 & 3.8 respectively (***Figure 3***).

Significantly, China has come down from a high energy intensity of 46.5 (1977) to 9.9 (2023), a reduction of 79% in 46 years, i.e., absolute average reduction of 1.7 intensity points every year. USA and Japan have also shown excellent downward energy intensity trends during the 46 year period (1977-2023), with reduction of 63% (USA: from 11.6 to 4.3) and 52% (Japan: from 7.8 to 3.8) respectively. On the other hand, during the same 46-year period, though India has also exhibited the downward trend, the rate of negative growth has been far less than desirable, at (-)20% only (from 15.3 to 12.2).

Figure 3: Energy Intensity of GDP (Petajoules per GDP (constant 2015 US$ billion): China, India, USA, Japan
Period: 1965 - 2023



Analysis and Chart by the Author, based on data from Energy Institute (2024) & World Bank Development Indicators Dataset 2024

The reduction in energy intensity may be due to structural/behavioural/weather/energy-mix/ energy efficiency issues[xiv] (US Dept of Energy Office of Energy Efficiency & Renewable Energy, 2024). Energy intensity is impacted by the structural changes, which address the differences in the economy's and end-use sectors' composition, e.g., shifting away from the energy intensive industries viz. metals, chemicals, fertilizers, cement, refining, etc. to less energy-intensive industries viz. machinery/equipment, textiles, food processing, etc. Behavioural changes deal with change of energy usage due to increase in affluence (more gadgets usage, hence more energy requirement) or age factors (older people may require more

heating in winters), etc. Improving the efficiency of homes, vehicles, appliances, etc. can also reduce energy intensity.

The GDP contribution of the manufacturing and industrial sectors has been declining over time. For USA, Industry & Manufacturing sectors' contribution to its GDP was 28% (2023 estimate), while the same for India is 38% and that of China is 65%[xv] (World Bank-World Dvpt. Indicators, 2023). Higher energy intensity of India's GDP (vs. China) can perhaps be explained by the efficiency of its equipment/machinery/appliances. A report from McKinsey, after examining the supply and demand for 55 different forms of energy in 30 sectors across 146 nations, indicated that 'reduction of energy intensity can be attributed to 4 key factors: 1) shift from industrial to service economy in fast growing countries viz. China & India; 2) technological changes resulting in substantial improvement in energy efficiency; 3) rise in electrification; and 4) growing use of renewables' (Namit Sharma et al., 2019)[xvi]. (Shiwei Yu et al., 2021)[xvii] in their study on the impact of renewable energy development on energy intensity in 82 major nations found that 'for every 10% increase in Renewable Energy development, energy intensity reduces by 0.3%'.

Needless to say, for a country like India, which aims to be *Viksit Bharat* with US$ 30 trillion economy, have per capita income of US$ 18,000-19000 per head by 2047, for which GDP has to grow at an average CAGR of 8.9% for next 25 years, higher energy usage per capita would be an essentiality. However, considering the pressure on emissions, there would be an urgent need to de-fossilize Indian economy and move towards renewable energy options, which will also help in reducing energy intensity.

One Third of Total Import (in Value Terms) of India is Energy

Energy imports (Oil, Gas, Coal) of India during 2023-24, at US$ 219 billion, contributed to 32.3% of total imports of India (US$ 678 billion)[xviii] (Ministry of Commerce & Ind. GoI, 2023). Such high energy import bill not only alters the trade balance, it also weakens the national currency and affects overall economic stability of the country. The energy prices have remained very volatile, especially during the last 50 years, e.g., after the Oil crisis of 1973, when OPEC countries imposed total oil embargo after the commencement of Israel-Arab war (Yum-Kippur war), crude oil prices took an upward turn. The average crude oil prices (US$/barrel) spiralled from US$ 3.3 (1973) to US$ 27.6 (1985) to US$ 111.7 (2012), down to US$ 43.73 (2016), and again went up to US$ 101.3 (2022) (Energy Institute, 2024)[xix]. Coal prices also have seen high volatility in line with the other energy prices; It went up from US$ 32 per MT (1998) to US$ 147.7 per MT (2008) to US$ 56.8 per MT (2015) to US$ 291.3 per MT (2022)[xx].

Rising energy costs not only drive inflation, as transportation and industrial production costs increase, they also erode the purchasing power of the average consumer due to rising consumer prices. Moreover, rising energy costs make a big dent on the purse of a country like India, which meets 1/3rd of its energy demand from imported sources. With respect to oil, during 2023, India consumed 249.3 million metric ton (MMT) of Oil, out of which only 32.6 MMT was sourced indigenously, implying 87% import dependency[xxi] (Energy Institute, 2024). To reduce dependence on imported energy, there is a need for the Indian economy to shift away from fossil fuels & invest in renewable energy options. This benevolent shift will not only enhance energy security of the Nation, but it will also create jobs domestically, contribute to

United Nation's Sustainable Development Goals (SDG) and reduce pressure on energy-fuelled inflation & Indian currency exchange rate.

Per Capita Energy Consumption & Emissions

In order to grow the wealth of an economy & meet the growing aspirations of the citizens to move up the ladder from a 'Developing Nation' to a 'Middle Income Nation' to a 'Developed Nation', a country invariably has to consume more energy. This has happened across the world over the decades. This is also evident from the per capita energy consumption comparison: while an average USA citizen consumes 277 gigajoule of energy per year , the same for a Japanese is 141 gigajoule/yr, 120 gigajoule/yr for a Chinese & 27 gigajoule/yr for an Indian (2023) [xxii] (***Figure 4***) (Energy Institute, 2024); i.e., an average Indian consumes 1/10th energy of an average citizen of USA, 1/5th of a Japanese and little less than 1/4th of a Chinese. This is directionally proportional to the per capita GDP (nom.) of the above countries: US$ 81695, 33834, 12614 & 2485 for USA, Japan, China & India respectively[xxiii] (World Bank-World Dvpt. Indicators, 2023) and also the per capita emissions of the above countries: 15089, 8840, 8423 & 2185 kg/head/yr for USA, Japan, China & India respectively[xxiv] (***Figure 5***) (Energy Institute, 2024).

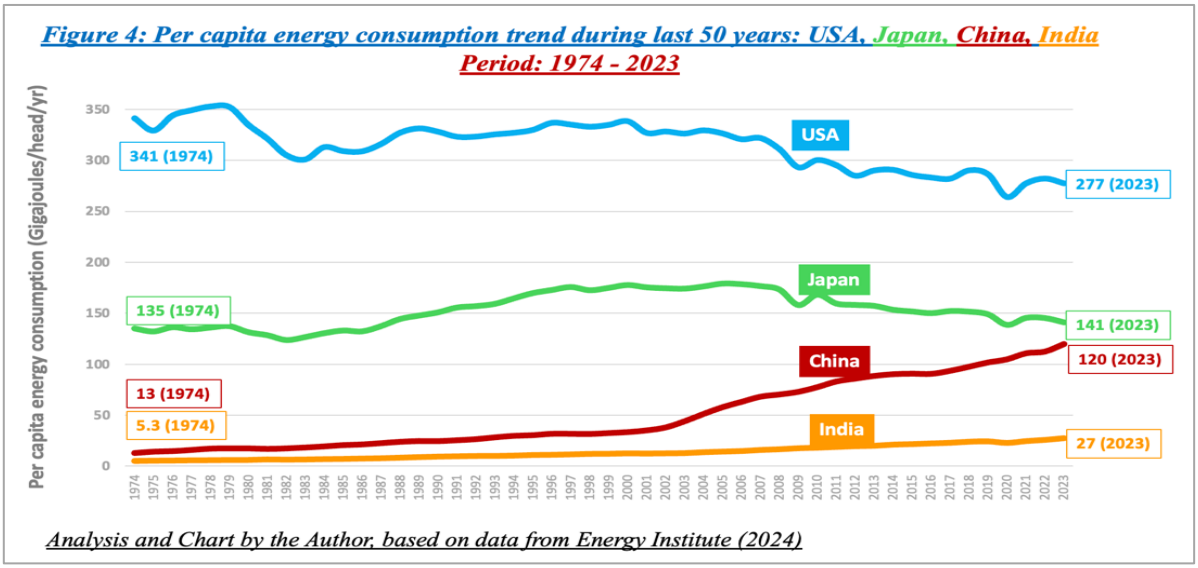
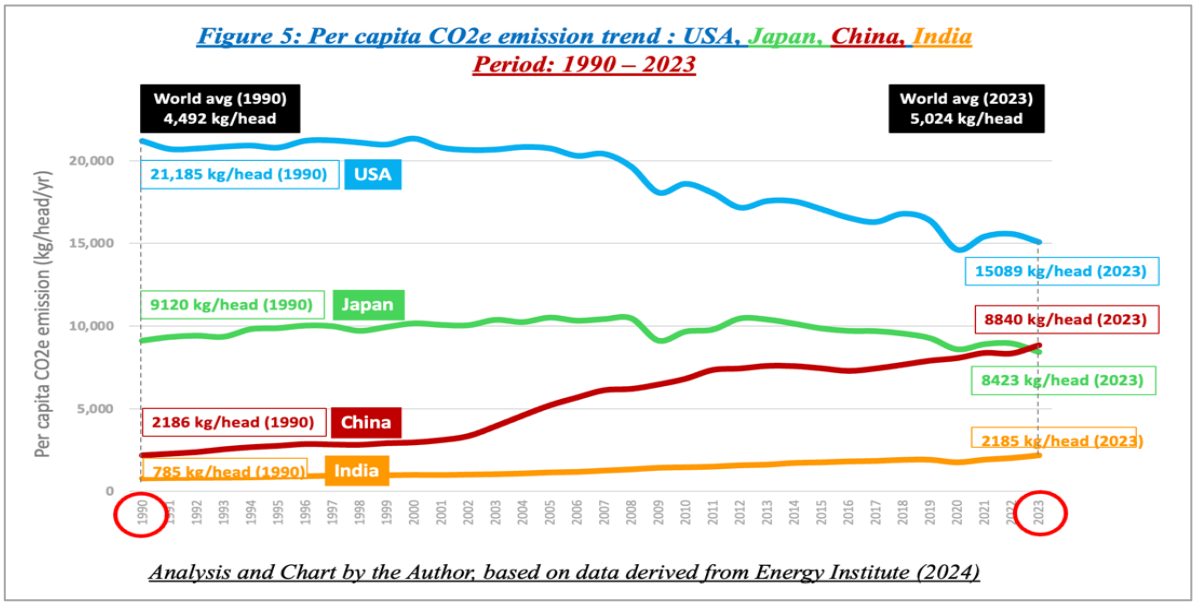


Figure 4: Per capita energy consumption trend during last 50 years: USA, Japan, China, India
Period: 1974 - 2023

Analysis and Chart by the Author, based on data from Energy Institute (2024)



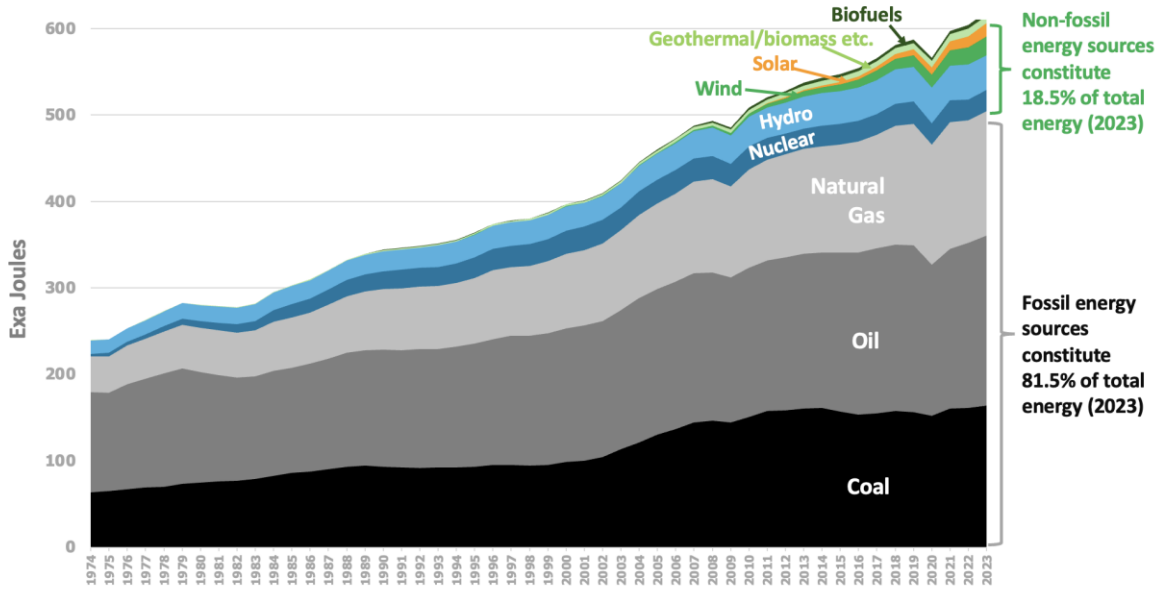
It is noteworthy that, the per capita energy consumption of an average USA citizen has come down by 19% [(-) 64 gigajoules] in last 50 years [from 341 gigajoules (1973) to 277 gigajoules (2023)], whereas that of an average Japanese has gone up by (+)4.4% [from 135 gigajoules (1973) to 141 gigajoules (2023)], that of an average Chinese has gone up by (+)823% [from 13 gigajoules (1973) to 120 gigajoules (2023)] and that of an average Indian has gone up by (+)440% [from 5.3 gigajoules (1973) to 27 gigajoules (2023)] (*Figure 4*).

Low per capita energy consumption is something that environmentalists would love to aim at. India's relatively benign position w.r.t. the per capita energy consumption is the key reason why the environmental footprint of India is much lower than that of the developed countries. India's low per capita energy consumption may be a blessing in disguise & good news for both the environmentalists as well as the Renewable Energy proponents. The environmentalists would argue that this is the best opportunity to keep the per capita emissions at the same level. The Renewable Energy proponents would like to lap up the opportunity to garner the entire new energy demand by putting up more renewable energy projects.

Overall Energy Consumption in the World – Fossil Dominance Continues

In 2023, World's Total Primary Energy Consumption (TPEC = Coal, Oil, Natural Gas, Hydro, Nuclear & Renewables) was 620 Exajoules (EJ, input equivalent)[xxv]. The fossil energy sources (viz. Coal, Oil & Natural Gas) constituted 81.5% of TPEC, whereas non-fossil energy sources (viz. Nuclear, Hydro & Renewables) constituted 18.5%[xxvi] [*Figure 6*].

Figure 6: Energy consumption (Exa Joules), source-wise [Last 50 years (1974-2023)]

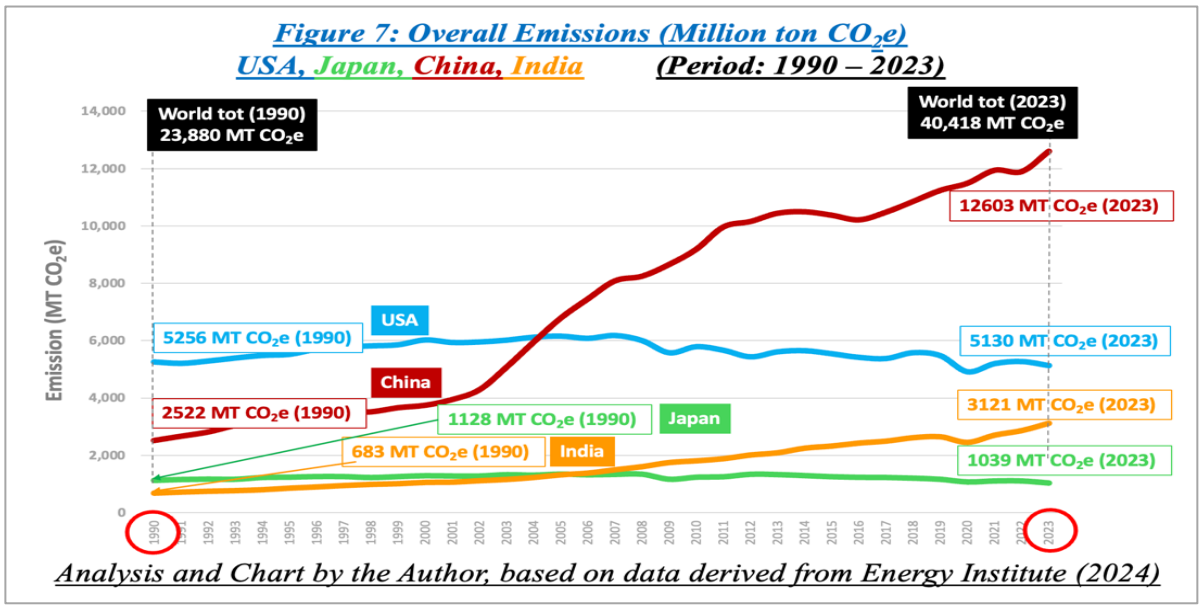


Analysis and Chart by the Author, based on primary energy data from Energy Institute (2024)

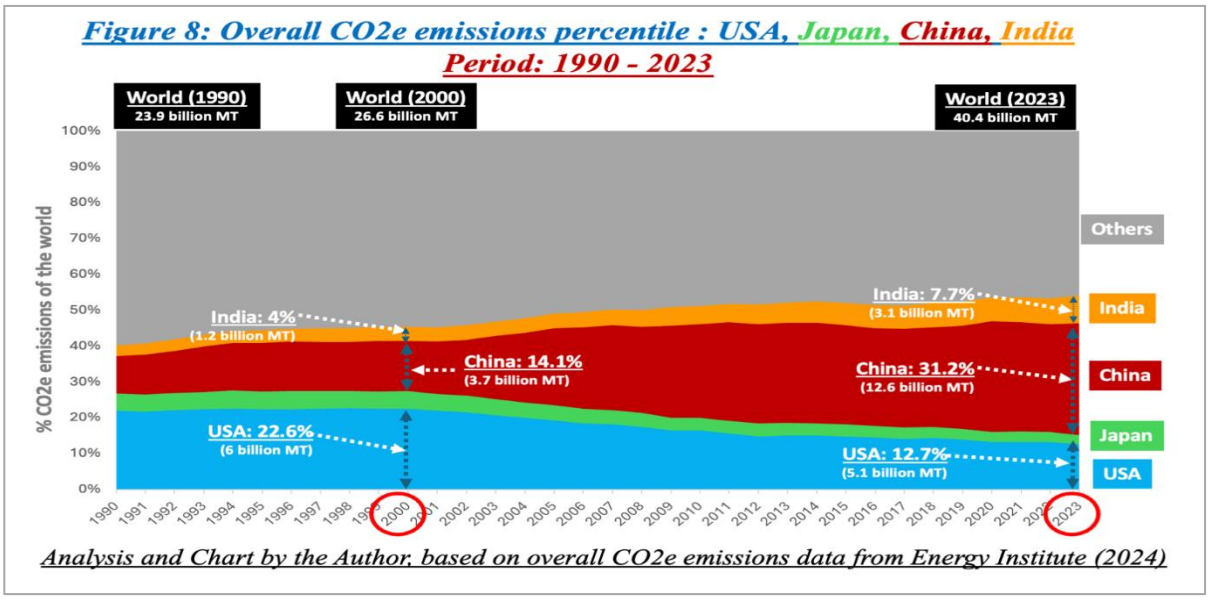
During the last 5 decades (1974-2023), TPEC has grown by 1.9% CAGR, out of which the last decade (2014-23) has recorded the lowest CAGR (1.2%), signifying, *inter alia*, improved efficiency of machinery, which use energy for our comforts/ requirements. During the same period, share of fossil energy (Coal, Oil & Natural Gas) in TPEC has not come down significantly despite rapid progress of renewables, especially during the last 2 decades. The share of fossil energy sources came down from 92.4% in 1973 to 81.5% in 2023 [i.e., reduction of 10.9% in 50 years, i.e., average of 0.2% per annum], is in favour of Renewables, viz. Solar, Wind, Geothermal, Biomass, Biofuels, Hydro & Nuclear.

Overall Emissions

Whereas many developed economies have reduced their overall emissions during last 34 years, developing countries have seen them rise (rationale: need to grow in line with the aspirations' of the populace). Total emissions of USA has come down from 5256 to 5130 Million Tonnes CO_2 equivalent (MT CO_2e) [drop of 2.4%] & the same of Japan has seen a drop of 7.9% during last 34 years (1990-2023). In contrast, emissions have increased by (+)357% for India and (+)400% for China during the same period (***Figure 7***). It is noteworthy that China surpassed USA w.r.t. overall emissions in the year 2005.



In line with the above trends, there have been significant changes in the contribution of emissions of key countries to the overall emissions, since the year 2000. During the period 1990-2000, the contribution of emissions of various countries were more or less constant (*Figure 8*). After take-off of Chinese manufacturing in a large scale from the year 2000, the shifts started to appear. During the period 2000 to 2023, the contribution of USA to the overall emissions came down from 22.6% to 12.7%, whereas that of China increased from 14.1% to 31.2% & that of India increased from 4% to 7.7%.



For an average Indian, while per capita energy consumption & hence per capita emissions are modest; in terms of overall emissions, India has been rising a little bit uncomfortably. During 2023, India's overall emissions was 3.1 billion MT, i.e., 60% of that of USA (5.1 billion MT).

The rapid increase in gross emissions of India can be gauged from the fact that a quarter century back, i.e., in the year 2000, USA's overall emissions, at 6 billion MT, was five times that of India at 1.2 billion MT. With the current level of emissions, i.e., at 3.1 billion MT (2023), India is the third largest emitter in the world, behind China (12.6 billion MT) and USA (5.1 billion MT). It is evident that for India to grow, energy consumption has to take an upward tick. However, the key question in front of the policy makers is: 'what should be the ideal energy-mix, which will enable economic growth along with meeting the Sustainable Development Goal (SDG) targets set by the United Nations and ratified by India'?

We wish to argue that the current energy/emission conundrum offers us a historical opportunity to shift away from fossil fuels at a reasonable pace and embrace Renewable Energy (RE) options & meet the twin goals of economic targets as well as SDG targets (especially w.r.t. the environment). In fact, the argument ('the need to accumulate economic wealth') citing which energy-consumption-votaries argue for more energy consumption (hence emissions), the same pitch can be construed as a blessing in disguise by the environmental-votaries, for targeting 'decent economic wealth' along with 'acceptable environmental health' through speedy Renewable Energy intervention.

'The Need to Emit More' Argument & Kyoto Protocol

The argument regarding 'the essentiality to increase per capita energy consumption by an average Indian' has often been: 'We, in India, have remained a part of the third world for too long and we aspire to grow to be part of a developed world, and in the process, higher energy consumption is a necessity, which cannot be denied.' To exemplify this argument, the rationale has been: The common Indian villager on bicycle and bullock cart would aspire to own a motorcycle one day & the common man in a town/city would aspire to graduate from a motorcycle to a car and also would like to go for aspirational consumer durables viz. AC, heater, fridge, washing machine, dryer, etc., all of which would require energy to run & would lead to more emissions. Such arguments have their political as well as economic ramifications, have lot of sensitivities attached and have been meticulously emphasized at various multi-lateral forums to put India's point of view in front of the world audience.

The attendant argument has been: "The environmental mess has not been created by India. It's the result of hundreds of years of unbridled industrialization in the USA and the Western world. They subsequently became 'developed nations' & in the process consumed huge quantities of energy & emitted large quantities of greenhouse gases, leading to 'global warming'. Therefore, the industrialised nations should shoulder the major responsibility for the environment's amelioration, not India". This rationale of the third world countries was accepted by the world at large, which led to signing & adoption of Kyoto Protocol agreements in 1997, which came into effect in 2005 after 7 years of negotiations & subsequent ratification by 160 Nations. This protocol paved the way for development of market based approach to reduce emissions (CO_2 and greenhouse gases) of the developed countries thru development of carbon markets across the developed world. The aim was to reduce overall emissions of CO_2 and other greenhouse gases of the industrialized Nations by at least 5% below the 1990 levels during the commitment period of 2008 to 2012.

The above arguments were sanguine till the time 'Global Warming' became a major buzzword, though the phrase was first propounded in 1975 by 'Wallace Broecker' of 'Columbia University's Lamont-Doherty Geological Observatory' in an article titled "Climatic Change: Are We on the Brink of a Pronounced Global Warming?"[xxvii]. The arguments regarding Kyoto Protocol agreements took a new turn, when populous countries viz. China & India's energy appetite led to large quantum of overall emissions, inching closer to/surpassing USA's emissions, which had remained the largest emitter in the world for many years. In the year 2005, for the first time, the overall Carbon Dioxide equivalent (CO_2e)[xxviii] emissions of China (6791 million tons) surpassed that of USA (6156 million tons)[Error! Bookmark not defined.], signifying a major, not-so-happy milestone for China.

In view of the above, the emission arguments shifted away from 'per capita energy consumption & emission' to 'overall energy consumption' and 'overall emissions' and hence the need to have shared responsibilities by all large Nations alike. This rationale led to large scale laudable voluntary adoption of renewable energy options with an aim to replace fossil fuels. However, even after more than 30 years of commencement of commercial solar/wind energy, renewables in the world contribute to only 18.5% of total primary energy consumption (2023).

Share of Solar & Wind Energy Needs to Rise Fast from the Current Level

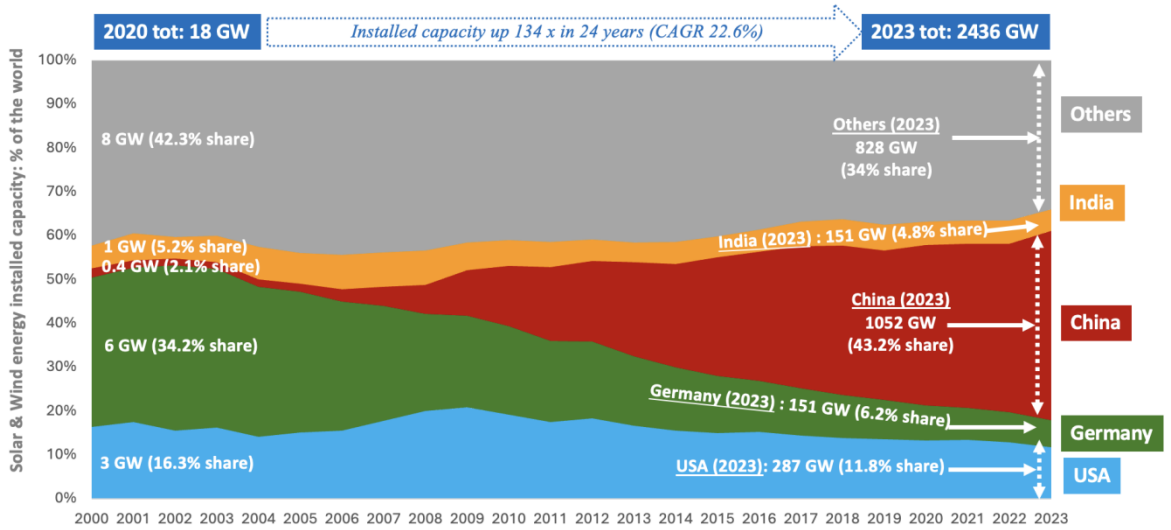
After about 40 years of commercialisation of Wind & Solar energy in the world, which started during the mid and late eighties, such renewables, today, constitute only 8.2% (= 50.6 exajoules) of world's total energy consumption basket (620 exajoules, 2023)[xxix]. If we include Hydro (6.4%) & Nuclear (4.0%) energy sources, the total non-fossil energy sources reach 18.5% (= 115 exajoules) of the total pie. Out of 50.6 exajoules of Wind & Solar energy consumed during 2023, 73.3% (= 37.1 exajoule) was contributed jointly by Wind (43%) & Solar (30.3%) energy. Balance renewables include Biofuels (2.3 exajoule, 4.5% share) and Biomass/Geo-thermal/etc. (11.2 exajoules, 22.2%). During the last decade (2014-2023), Renewable Energy consumption registered higher growth of 3.8% CAGR as compared to other energy sources. Amongst Renewable Energy sources, Solar (23.1% CAGR) and Wind (12.2% CAGR) registered much higher decadal CAGR than other RE sources, viz. Geothermal/Biomass (4.5%) & Biofuels (4.3%).

Solar technologies and its scale of operations have made giant strides since its commercial scale inception in the mid-nineties. Especially during the last decade (2014-2023), energy consumption from solar sources has gone up 8x, from a low base of 1.9 EJ in 2013 to 15.34 EJ in 2023. Though the growth of solar energy consumption has been spectacular during the last decade (23.1% CAGR, 2014-2023), after more than 3 decades of solar energy commercialization, its share in the world's Total Primary Energy Consumption (TPEC) basket in 2023 was only 2.5% [15.3 EJ out of 620 EJ]. India, whose solar journey started modestly in the year 2011 (0.01 EJ consumption), fares slightly better than the world, as its solar consumption share in its TPEC basket was only 2.7% in 2023 [1.06 EJ out of 39.02 EJ] (Energy Institute, 2024).

China's Contribution to Renewables

China has made giant strides in its Solar and Wind energy journey during the current millennium. During the year 2000, China's share of Solar & Wind energy (combined) installed capacity in the world was only 2.1% (= 0.4 GW). Within the next 23 years, China could multiply this capacity by 2800x, to reach 1,052 GW. At the end of 2023, China's Solar and Wind installed capacity share in the world stood at 43.2%[xxx] (Energy Institute, 2024) (***Figure 9***). Notably, in the year 2000 (early days of Solar & Wind), when world's total Solar & Wind installed capacity was only 18 GW, Germany dominated the scene with 34% share, followed by USA @ 16%. Then, India's share in the world, @ 5.2%, was more than double that of China (2.1%). China has moved the mountains in the next two decades, to be the torch bearer of Solar & Wind energy & become the Solar & Wind manufacturing as well as consumption hub of the world. And India, though has grown significantly from 0.9 GW (2000) to 118 GW (2023) in 23 years, with CAGR of 22%, India's share has decreased marginally from 5.2% to 4.8%. China's appetite for Solar & Wind energy capacity addition can be gauged from the fact that during one single year (2023), China could add 293 GW capacity, which is more than the entire Solar & Wind installed capacity of USA in 2023 (287 GW), twice that of Germany (151 GW) and 2.5 times that of India (118 GW).

Figure 9: Solar+Wind installed capacity : USA, Germany, China, India
Period: 2000 - 2023



Analysis and Chart by the Author, based on Solar & Wind energy installed capacity data from Energy Institute (2024)

India's Impressive Solar & Wind Energy Journey

India started its Wind & Solar energy journey of some significance in 1990 & 1995 respectively. By the year 2000, Solar & Wind installed capacity was 0.9 GW (5.2% of the world) & electricity generated was 2.1 terawatt-hour (4.9% of world)[xxxi]. 23 years later, i.e., by the year 2023, Solar & Wind energy installed capacity has increased to 118 GW (16.2% CAGR), though India's share in the world has marginally come down from 5.2% (2000) to 4.8% (2023). Electricity generation from Solar & Wind has increased from 2.1 terawatt-hour

(in the year 2000) to 196 terawatt-hour, with CAGR of 17.7%; however, India's Solar & Wind generation share in the world has remained constant at 4.9% [xxxii] (Energy Institute, 2024).

The growth of Wind & Solar energy in India, since the year 2000, has been significant (17.7% CAGR), albeit with a lower base. Even if one considers last 10 years (2014-2023), the growth has also been noteworthy (16.2% CAGR). Out of top 4 countries with respect to Solar & Wind energy installed capacity, only China catapulted thru the barrier & grew at 23.7% CAGR; India (16.2%), USA (13.3%), Germany (7%) also clocked decent CAGR during last 10 years (2014-2023).

At the end of 2023, India stands as the 4th largest country with respect to Solar & Wind energy installed capacity (118 GW). Though the growth has been impressive so far (although with low base), there are technical, commercial, policy & attitude issues in the way of scaling up of renewables in the country, notable amongst them being: grid integration, affordable green financing, simplified policy framework, ease of acquiring land, intermittency of production (hence storage option, which is expensive now), consumers attitude towards renewables, etc.

Commitment towards Net Zero by Various Countries

The 195 participating member states and the European Union unanimously endorsed the "Paris Climate Accord" during the 2015 Conference of Parties (COP) in Paris (COP21), which states that the long-term objective is to keep the rise in mean temperature to "below 2^{0}C" (vs. the pre-industrial levels) and preferably limit the increase to 'less than 1.5^{0}C'. Such an objective would essentially entail reduction in greenhouse gas emissions, most of which are emitted due to large-scale usage of fossil fuels. In order to achieve the larger goals of emission reduction & limiting temperature rise, various countries across the world have declared their 'Net-Zero' targets. Hon. Prime Minister of India, during COP26 (2021) held at Glasgow, Scotland, announced that India will achieve its net zero target by 2070. USA & China have declared their Net Zero targets as 2050 and 2060 respectively. All signatory nations have pledged for the first time at COP28 in Dubai in 2023 to transition away from fossil fuels in a "just, orderly, and equitable manner" in order to lessen the worst effects of climate change and achieve net zero by the middle of this century, i.e., 2050.

For the year 2023, out of world's emission of 40.4 billion tons, 86.9% (i.e., 35.2 billion tons) was from fossil energy sources viz. Oil, Gas & Coal[xxxiii]. For achieving Net Zero objectives, usage of fossil-based energy must come down drastically, which would necessitate large-scale scaling up of renewable energy infrastructure (viz. Wind, Solar, Biofuels & Geothermal); Such renewables, during 2023, constituted only 8.2% of the total energy consumption of the world [out of which, Solar constituted only 2.5%]. In India, for the year 2023, Renewable Energy consumption constituted only 6.1% of total, out of which contribution of Solar was 2.7%.

Solar to hold Primacy for Moving towards Net Zero

Govt. of India has set its aims to be a Net Zero country by 2070, which means moving away from the fossil fuels and increasing the proportion of renewable energy sources in its energy mix, implementing more energy-efficient measures, and encouraging sustainable management practices across the board. As on 30th Nov 2024, out of total electricity generation installed

capacity of 457 GW, share of non-fossil energy sources was 46.8% (=214 GW), out of which Wind & Solar contributed 31.1% (=142 GW)[xxxiv] (Ministry of Power Govt. of India, 2024). However, considering that the plant load factor (efficiency) of wind and solar is in the range of 20-25% & that of thermal power plants is in the range of 60-65%, the actual contribution of Wind & Solar in total electricity generation would be much less than the ratio of installed capacity.

Wind energy is site-specific & most of the good wind sites (with viable wind speed of 4-6 meters/second) have already been taken by corporates/other entities for putting up wind power plants. Off-shore wind power plants provide an opportunity, but they are very expensive and entire east coast & some parts of west coast of India, being cyclone prone, may be high risk proposition for installing such off-shore plants. Other renewable energy options viz. Biofuel/Geothermal/Hydro face challenges of competing resources viz. land/water/pesticide/ecology/etc., site-specificity (e.g., specific areas having tectonic activity, river basin, etc.), and entail higher upfront capital investment with the existing processes/technologies and challenges of scaling-up.

In contrast, solar energy ticks most of the right boxes. India, being a tropical nation, receives generous quantum of sunlight throughout the year, making it one of the best geographies for setting up of solar power plants. Majority of its regions receive abundant amounts of sun radiation all year long[xxxv] (Raina & Sinha, 2019). However, India is yet to harvest its solar energy to its true potential and can emulate/surpass many countries in the world, who have very well exploited their limited sunshine potential, e.g., Germany, with only 1547 sunshine hours per year[xxxvi] (for the 12-month period from Mar-2023 to Feb-2024), as much as 10.5%[xxxvii] electricity comes from solar sources (2022); and for Japan (1872 sunshine hours per year[xxxviii]), the ratio was 9.9%[xxxvii] (2022). In contrast, India, with 2618 sunshine hours per year[xxxix], sourced only 5.1%[xxxvii] from solar energy(2022).

Moreover, unlike wind power, solar can offer decentralized energy solutions, such as rooftop/village centre installations, which can make energy available at the place of consumption, thereby minimising transmission losses. Additionally, Solar energy scores positively in many ways, due to a) ease of accessibility, i.e., solar panels can be put up anywhere; b) modular/scalability, i.e., solar panels can be deployed at various sizes, from small installations on the rooftop to large gigawatt-scale plants; c) low in maintenance (no moving parts, only cleaning of panels required), and d) solar can be deployed on off-grid mode, for rural and inaccessible areas. Considering the challenges of rural electrification, solar energy can not only provide a befitting solution to meet the energy needs of the rural as well as denizens of India, it can also help to create a thriving ecosystem for manufacturing, job creation & overall socio-economic development and be the energy of choice for moving towards the Net Zero objectives.

Conclusion

India must strike a careful balance between promoting growth and reducing the negative environmental effects of increased energy use, as it works toward being a US$30 trillion economy by 2047. Historically, we have rightly argued that, given our low per capita emissions, our developmental necessities outweigh the Green House Gas emission reduction demands to

justify our increase in emissions. The Kyoto Protocol era recognised this argument. However, the rise in India's overall emissions and worldwide worries about climate change has forced the need to identify sustainable energy paths.

The majority of India's primary energy use still comes from fossil fuels, which increases import costs and maintains a strong reliance on unstable international markets. Therefore, it is essential to develop a dependable, scalable, and cleaner substitute in order to protect India's ecological future, public health, and economic stability. While geothermal, hydro, wind, and bioenergy play a part in the nation's renewable energy mix, their use is limited due to issues viz. site-specific factors, high capex and maintenance costs, etc. In comparison, solar energy appears to be the most appropriate & adaptable renewable energy solution, at present. Its ability to be deployed in decentralized mode, through rooftop installations or small-scale community grids, can fill in the gaps in rural electrification and provide energy solutions even to the most remote regions of the nation. India's expanding industrial and service sectors can be powered by gigawatt-level capacity produced by large-scale solar installations. Solar power can also overcome its intermittency issues as production costs further come down, technology advances, and cost of storage becomes reasonable.

However, achieving solar primacy would require coordinated policy assistance, ranging from financial incentives for local production of photovoltaic components to expedited clearances and land-acquisition procedures. Reliability will be further improved by further research on grid-scale energy storage. Rapid solar expansion, if done carefully, can not only decarbonize India's economy but also boost local manufacturing, create jobs, and improve the country's energy security. In fact, solar energy can potentially be the key component of India's plan for inclusive and sustainable growth, enabling the third-largest energy user in the world to innovate its way to a cleaner future and keep its commitments under the global Net Zero paradigm.

References

1. [i] World Economic Outlook, April 2024, published by International Monetary Fund
2. [ii] Author's analysis based on data on GDP (constant, 2015 US$) at current dollars (2023 est.) published by World Bank in its World Development Indicators dataset, 2024
3. [iii] The Hindu (29th Jan 2024): citing Ministry of Finance, Govt of India
4. [iv] Press release dt 26th July 2024 by Public Information Bureau, Govt. of India
5. [v] Author's analysis based on data on per capita GDP (Nominal, 2023) published by World Bank in its World Development Indicators dataset, 2024
6. [vi] LRRDIS Parliament Ref Note Govt of India. (2023). Vision India@2047: Transforming the Nation's future.
7. [vii] DGFT Ministry of Commerce & Industry Govt of India. (2024). Monthly Bulletin of Foreign Trade Statistics
8. [viii] Journal article "The Relationship between Energy Production and GDP: Evidence from Selected European Economies" by Grażyna Szustak, Piotr Dąbrowski, Witold Gradoń and Łukasz Szewczyk; published in MDPI, Dec-2021
9. [ix] Article in McKinsey Quarterly "The decoupling of GDP and energy growth: A CEO guide" by By Namit Sharma, Bram Smeets, and Christer Tryggestad; April-2019

10. [x] 1 Exajoule = Energy of a quintillion joules; 1 Exajoule = 10^{18} joules; 1 Petajoule = 10^{15} joules
11. [xi] Author's analysis based on data published by Energy Institute, 2024 [https://www.energyinst.org]
12. [xii] Author's analysis based on World Bank data on 2023 GDP (Constant 2015 US$); published by World Bank in its World Development Indicators dataset, 2024
13. [xiii] 1 Petajoule = 10^{15} joules
14. [xiv] Energy Efficiency vs. Energy Intensity by US Dept of Energy Office of Energy Efficiency & Renewable Energy, 2024 (www.energy.gov)
15. [xv] Author's analysis based on data on sectoral GDP contribution (2023 est.) published by World Bank in its World Development Indicators dataset, 2024
16. [xvi] Article in McKinsey Quarterly "The decoupling of GDP and energy growth: A CEO guide" by Namit Sharma, Bram Smeets, and Christer Tryggestad; April-2019
17. [xvii] 'Does development of renewable energy reduce energy intensity? Evidence from 82 countries'; by Shiwei Yu, Jie Liu, Xing Hu, Peng Tian ['Center for Energy Environmental Management and Decision-making', China University of Geosciences, Wuhan and School of Economics and Management, China University of Geosciences, Wuhan], 2021
18. [xviii] 'Export-Import Data Bank, Ministry of Commerce & Industry, Govt. of India'
19. [xix] Crude Oil prices 1861-2023 by Energy Institute
20. [xx] Coal & Uranium prices 1987-2023 by Energy Institute
21. [xxi] Oil Production & Consumption 1965-2023 by Energy Institute
22. [xxii] Author's analysis based on data published by Energy Institute [https://www.energyinst.org]
23. [xxiii] Author's analysis based on World Bank data on 2023per capita GDP (Nominal); published by World Bank in its World Development Indicators dataset, 2024
24. [xxiv] Author's analysis based on data published by Energy Institute [https://www.energyinst.org]
25. [xxv] ''Input-equivalent' energy is the amount of fuel that would be required by thermal power stations to generate the reported electricity output'.
26. [xxvi] Author's analysis based on primary energy consumption data from Energy Institute [www.energyinst.org]
27. [xxvii] NASA, educational article at https://gpm.nasa.gov "What's in a Name? Global Warming vs. Climate Change",23rd June 1988
28. [xxviii] CO_2e = 'Carbon Dioxide equivalent' = 'sum of carbon dioxide emissions from energy & flaring, methane emissions (in carbon dioxide equivalent) associated with the production, transportation and distribution of fossil fuels, and carbon dioxide emissions from industrial processes'.
29. [xxix] Author's analysis based on data on Primary Energy Consumption by Fuels (2023) published by Energy Institute [www.energyinst.org], 2024,
30. [xxx] Author's analysis based on data on historical Solar and Wind energy installed capacity, published by Energy Institute [www.energyinst.org], 2024
31. [xxxi] Author's analysis based on data on 'historical Solar and Wind energy installed capacity', published by Energy Institute [www.energyinst.org], 2024
32. [xxxii] Author's analysis based on data on 'historical Solar and Wind energy installed capacity & generation, published by Energy Institute [www.energyinst.org], 2024
33. [xxxiii] Author's analysis based on data from Energy Institute [https://www.energyinst.org]
34. [xxxiv] Power sector at a glance (30th September 2024), by Ministry of Power, govt. of India

35. [xxxv] Raina and Sinha, 2019
36. [xxxvi] Statista [https://www.statista.com], quoting 'The German Weather Service' ['Deutscher Wetterdienst, https://www.dwd.de/'], Federal Ministry for Digital Affairs and Transport, Govt. of Germany.
37. [xxxvii] Author's analysis based on data from Energy Institute [https://www.energyinst.org]
38. [xxxviii] Current Results [https://www.currentresults.com/], quoting Japan Meteorological Agency; Long-term historical averages for 60 cities/ towns of Japan, for the period from 1981 to 2010.
39. [xxxix] Current Results [https://www.currentresults.com/], quoting India Meteorological Department and World Meteorological Organization; Long-term historical averages for 18 cities/towns of India, for the period from 1961 to 1990.