Renewable Energy in India: Resource Availability, Waste Generation and Management

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Abstract: Energy security, environment and economy are the three major pillars of a country. These parameters not only secure a better quality of life for the citizens but also protect the country against an unwanted threat and economic crises. The energy need in India is primarily fulfilled by burning of the fossil fuels, but their reserves are limited and may deplete very soon. Also, they emit a large amount of CO_2 gas in the environment which is a key driver for the global warming. Therefore, to sustain the economy and protect the environment, India is focusing on the use of renewable energy; particularly solar and wind energy. In this article we have assessed the potential of these two energy sources in terms of material availability, waste generated and its disposal. At the end we have compared it with the well-established nuclear energy technology. Finding the future of a technology based on the raw material availability and its final treatment is necessary to make a self-reliant and sustainable technology, as India is progressing towards the same.

Keywords: Energy, Renewable, Global Warming, Material, Waste.

1. Introduction: Energy generation is one of the biggest challenges in today's world because its demand has increased remarkably in the past. To put forward the numbers: global energy consumption was about 146 EJ (1 EJ=23.9×10^6 metric tonne oil equivalent) in year 1960 but has increased to 556.63 EJ in 2020 [1]. It has been predicted that the demand will further increase nearly by 50% in 2050. Total energy consumption of a country is driven by two factors (1) Population, (2) Energy spent per capita. Both these factors differ among countries depending upon their geographic location, technological advancement and, availability of resources. Henceforth; the need and the way to transform the energy industry also varies and a unique transformation path cannot be applied to all the countries together. Figure 1A shows a general trend of population growth and energy demand for different group of countries in near future. It can be seen from Figure 1A that in the Organisation for Economic Co-operation and Development (OECD) countries, Europe and Eurasia and America, the population is almost constant however in Africa, Middle East and Asia population growth is forecasted. In these group of countries the energy consumption is also predicted to increase as compared to other countries and among them Asia will see the greatest expansion with ~40% of the world energy share by 2040 [2]. The majority of this share will be from China and India because of their, fast developing economies and high population. Figure 1B shows the energy consumption in the past and future for both these countries. Although from year 2000-2020 the energy demand in China has increased sharply but after that the growth projection is predicted to follow a linear increase however, in case of India it might increase exponentially. It is to be noted that by year 2025 the Indian population will surpass that of China to become the world's most populated country. The growing population and industrialization will result in more future energy demand for India. Presently, fossil fuel burning is the major sources of energy generation in India but their reserves are limited and it is estimated that with the current consumption rate the reserves will last only for 105 years in India [3]. Energy generation by fossil fuels is also one of the biggest contributors to CO_2 emissions and by an estimate account for around three-quarters of greenhouse gas emissions today and holds the key to averting the worst effects of climate change [4].

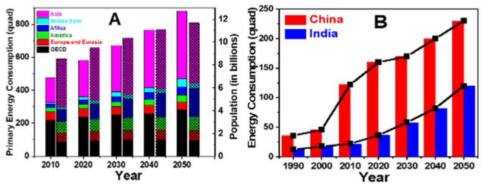

Figure 1A. Primary energy consumption and population growth in different group of countries in past and future years projected. 1B. Primary energy consumption in India and China in past and future projections.

It can be predicted with certainty that in future we will witness further increase if proper measures are not taken now. Various laws and climate policies are formed to regulate the emissions but the way these responsibilities are shared among different regions, countries and individuals is questionable. This is because the emissions differ for different countries and their per capita [4]. To compare, in 2020, China was one of the largest CO_2 emitters (Supporting Information (SI) Figure SF1A) but the per capita emissions are maximum for the Unites States (SI Figure SF1B). Although, India is much below the world average per capita CO_2 emissions but considering increasing population and industrialization, the emissions are predicted to increase creating an alarming situation for public health. The worse effects of climate change are even observed today.

Energy is also closely related to the economy as it ultimately enables investments and technologies that create jobs and drive growth among countries. Gross domestic product (GDP) of a country is a measure of economic growth. Many studies have been carried out in the past to understand the relationship between energy consumption and GDP [5–7]. It was observed that India is an energy dependent economy and portrays a bidirectional causal relationship between energy consumption and GDP [8]. It is postulated that the Indian economy will grow at the rate of 5% per year in comparison to world average of 3% and to achieve this growth, India needs massive amount of energy [8].

2. Solar and Wind energy contribution in India: Considering the stated facts together, it is certain that India needs large amount of energy to cater to its needs and in order to maintain the health of the environment a shift from fossil fuels to other low carbon or CO_2 neutral energy sources is absolute necessary. The primary condition is that the sources should be deployed economically and generates energy in a sustainable manner. For this, energy sources such as solar-photovoltaics, concentrated solar power, wind, geothermal, hydroelectric, wave, tidal, nuclear, corn-ethanol, cellulosic-E85 and coal with carbon capture and storage technology have been explored in India and their potential is evaluated in terms of various parameters such as abundance, scalability, greenhouse gas emissions, land use and, technological advancement [9]. Based on these parameters, it was found that the solar and wind energy has the largest potential for India because of their ultimate renewability and large scalability [9–11]. Considering this, Indian government is promoting these technologies and many solar and wind energy plants have come up in recent years. Researchers have also evaluated the potential of these two energy sources for India using different approaches. Lu et. al. [11] have used the cost optimization model to evaluate the best possible energy mix for India, taking cost, storage, power demand, inter-regional grid connectivity and capacity factor into account and suggested that 80% of the India's energy demand in 2040 can be met by renewable; in particular solar and wind energy. In their prediction they have assumed that the combined energy output of these two sources will be 3800 TWh assuming a growth rate of 6.5% per annum. We did a calculation wherein the actual energy generated from these two sources in 2021 and 2022 was taken [12] and the same growth rate factor was applied (Supplementary Sheet 1, SI). From the calculation it was found that the combined energy potential of these sources in 2040 will be 484.15 TWh; almost 8 times less the value taken by Lu et. al. for designing energy distribution in India. To look into it further, we checked the growth of solar and wind energy in last 10 years in India and their contribution in the installed capacity for electricity generation and in total energy consumption per year in electricity sector (Supplementary Sheet 2, SI). The results are plotted in Figure 2. It is evident that the wind energy is almost at its saturation and its growth and use in electricity sector is almost constant. In fact its contribution in the overall electricity generation has decreased in past two years (Figure 2C) which suggest that this sector is not growing as per the rate at which electricity demand is growing. Looking at the solar energy, it is seen that this sector has seen a remarkable growth in last 5 years and the growth rate of as high as 80% has been achieved. Thanks to the geographical location of India because of which solar energy is available in surplus amount. Figure 2B shows that the contribution of solar energy in total installed power (GW) is >14% however, the overall energy generated per year is much less ~4% in 2021. This is because of the interim nature of this energy source and the energy is not available all the time to extract.

A detailed analysis on the growth trajectory of solar and wind energy sources in different countries has been carried out by Cherp et. al. [13]. They have shown that it follows S-shaped curve where initially the growth will be slow; then it accelerates followed by saturation. The same type of growth pattern has also been observed as shown in Figure 2C. From the results it is seen that the wind energy has attained a stable growth while solar is in its growing phase. Cherp et. al. [13]. have also shown that the maximum growth rate that wind and solar energy can attain in a large country like India is ~1% and 1.1%, respectively of the total electricity output. Considering this fact and the contribution of solar and wind energy in the total electricity generated (GWh/y); ~4% in 2021, it is envisioned that these two sources in total will contribute maximum 50% to the total electricity output by 2040 as against the ambitious estimation of 80% suggested by Lu et. al. [11]. This suggests that a technological innovation and better planning is needed to achieve the much higher growth rates. Jacobson et.al. [10] have mentioned that 100% energy demand by 2035 can be met by renewable particularly wind, water and solar energy. For the study they have considered electrification of most of the processes including heating and cooling and transport as well as collaboration among different countries. For example India is grouped with Bangladesh, Sri Lanka, and Nepal but considering today's geopolitics nothing can be assured. Also, looking at the current energy distribution in India, this seems to be a highly ambitious estimation. Tiewsoh et. al. [8] have used the long-range energy alternative planning (LEAP) model for predicting the contribution of various energy sources in electricity generation for India in 2030 and commented that solar and wind energy are the major renewables for India but the contribution from nuclear energy cannot be ignored because of its continuous supply and ~9-15% contribution in the overall electricity generation which will come from this sector. Here we would like to emphasise that in 2021 the power sector represents only 18.2% of the overall energy consumption [14,15] in India. As India along with the world is trying to move more towards the processes driven by the electricity, in future the electricity demand will increase further that in turn will require more energy from renewable and low carbon energy sources. Therefore, it is important to understand the advantage and limitations of these energy sources to reach to a better planning.

The merits and demerits of an energy source are decided by many factors as described in Figure 3. Many of these parameters such as availability and scalability, greenhouse gas emissions, water use, effect of climate, public acceptability and job creation for different energy sources has been discussed earlier by many researchers [1,8,9,11,13,16,17] and in detail by Jacobson et. Al [9]. Herein, we will forecast the future of solar and wind energy sources for India by evaluating their performance in terms of various parameters that connects the GDP, energy and environment together. Our major focus will be on material availability, and waste generated as these parameters are of equal importance to

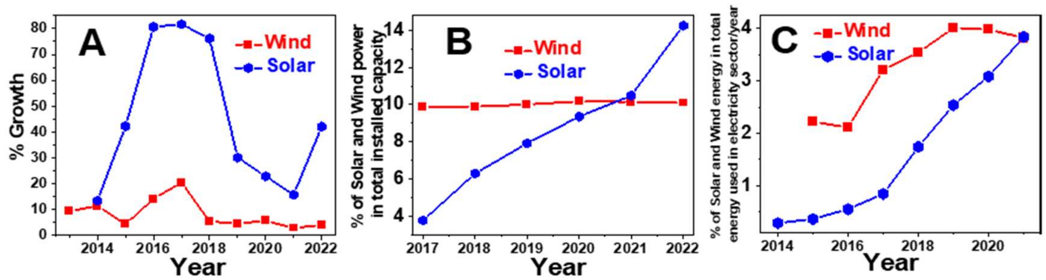

Figure 2A. % growth of solar and wind energy. 2B and 2C. % Contribution of solar and wind energy in installed power (GW) and total energy (GWh/y) used in electricity sector respectively.

preserve the biodiversity and sustain the economy in a densely populated country like India. We will be very brief with other parameters and only mention wherever required.

2.1. Solar energy: First, we will discuss the solar energy. Solar energy is the conversion of sunlight into electricity using photovoltaics (PV), or concentrated solar power (CSP). This idea was led by the discovery of photovoltaic effect in 1839 [18] and the first solar cell based on silicon was reported in 1954 with an efficiency of ~6 % [19]. Since then the solar cells have shown a commendable improvement and now contribute ~3.4% of the world electricity share which was ~ 0.01% in 1990 [16,19,20]; and anticipated to reach 25% by 2050 [1,16,19,21]. The potential of solar energy can be understood by the fact that an one hour equivalent of this energy was more than the energy used by the world in one year [21] and because of this it is sought as one of the important contributors in energy mix, particularly in India because of high intensity reaching the surface. However this energy source is not available all the times and the fluctuation pose a major limitation in using solar energy to meet the continuous demand. Capacity factor is an important term that basically measures how often a plant is running at maximum power compared to its nameplate potential. It is a measure of reliability of a plant. A plant with capacity factor of 100% means it is producing maximum power all the time.

Capacity Factor = Actual unit electricity output/Maximum possible output.

Capacity factor for solar energy is calculated for last 8 years in India (Supplementary Sheet 3, SI) and it was observed that the value ranges between 11-18% which means that the maximum energy that can be drawn from solar is much less as compared to their nameplate potential. Moreover, this energy is not in continuous supply that poses a major limitation on grid stability and powerful storage batteries are needed to store solar energy. Numerous research is also going on to develop techniques

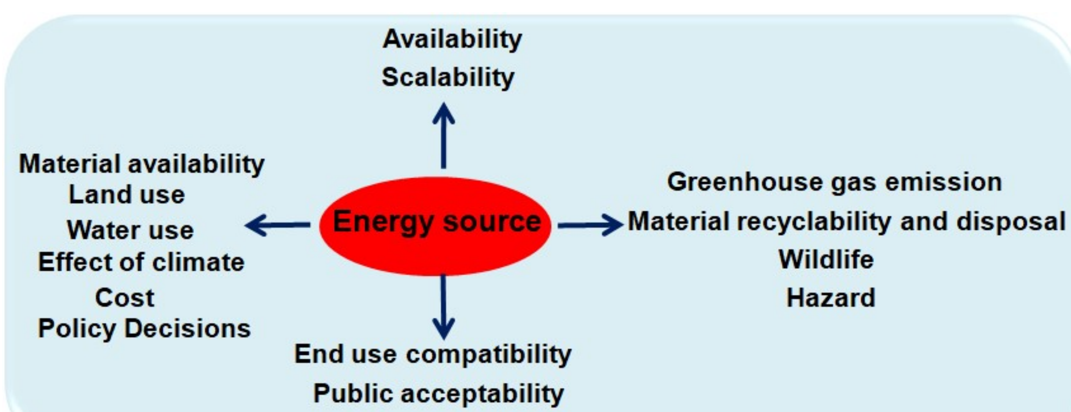

Figure 3. Various parameters to evaluate the performance of an energy source.

that can convert solar energy into hydrogen via water splitting in electrolyzers and use directly hydrogen as a fuel [22]. But it has not come in the public domain yet.

Let us talk about the materials needed for solar energy harvesting. First of all, a suitable material that absorbs the solar energy and converts it into useful power with high efficiency is needed. Of all the materials discovered [16,22,23], silicon is the most used material and silicon-based solar cells (mono and poly-crystalline silicon) cover over 80% of the world's installed capacity today [16]. CdTe, CuInSe and CuInS are also prominent materials for solar energy harvesting because of their low cost and better mechanical properties, but have low efficiency. Several advanced technologies such as dye sensitized solar cells, quantum dot solar cell, perovskite based solar cells, organic solar cells etc. [22] have been developed for solar energy harvesting. They have been tested on laboratory scale and are yet to emerge at the plant scale. Today, Si, Cd, Te, In, and Cu are the main components of a solar cell absorbing material. Ag is used in solar cell solution as electrolyte. So for solar cell technology to grow and reach at its maximum potential these elements should be available. If we look at the reserves for these elements; as of 2021 Ag reserves in total is 5,30 billion tons out of which 4,74 billion ton is mainly concentrated in Peru, Australia, Russia, China, Poland, Unites States, Mexico, Chile and Bolivia [24]. In India, there are no native silver deposits except the small and unique Bharak deposit in Rajasthan with an estimation of ~29000 tons. Also it is estimated that the Ag deposit will be completely washed off in next 200 years and the world will reach at the same scenario as that of fossil fuel for now [25].

Silicon is abundantly available in nature but mostly found in SiO_2 form. Solar cell needs silicon in highly purified form. Silicon purification is an extremely difficult and energy intensive process. The market is majorly dominated by China and in 2019 it produced ~4.5 million tons of pure silicon that accounted for ~64% of global production. Though India is among the top 15 producers, its production was 60,000 tons which is <1% of global production (7 million tons) in 2019 [24]. India has imported most of its solar cell material from China in the past few years. Although the government is putting a lot of efforts for the local self-reliant technology still the correlation between the technological development, its implementation and demand looks far from the meeting point.

For thin film solar cell, Cd, Cu, In, Se and S are needed. Cadmium is generally recovered from zinc ores and sphalerite is the most economically significant zinc ore mineral for Cd recovery. The world production of cadmium was estimated at 25,600 tonnes in 2018. Most of the world's primary cadmium is produced mainly in China, Republic of Korea, Japan, Canada, Kazakhstan, Mexico, Russia and Peru. India has imported ~6,904 tonnes of Cd in 2018-19 from China, Japan, Republic of Korea, Mexico and Peru [24]. Indium is also majorly produced in China followed by South Korea and Canada. Cu is produced majorly in Chile, United States, Indonesia and Peru. In Se production also United States, China, Germany, Japan, Belgium, Russia are the leaders. This suggests that most of the materials used for solar cell fabrication are either not present or not manufactured in India and for solar cell technology, India is heavily dependent on the imports from other countries. Figure 4 shows on maps the important materials for solar energy along with their reserve sites.

2.2 Wind Energy: Let's move to the other renewable energy source that is wind energy. Wind is considered to contribute significantly in fulfilling the future energy demand. Even today, it is one of the major contributors of renewable energy share in the total energy portfolio. Wind farms consist of both onshore and offshore wind farms. Onshore wind power generates electricity using wind farms constructed on land which require a large amount of land and high wind speed. In most of the cases these wind farms are constructed in rural areas that can lead to habitat loss and compete with other usages of the land.

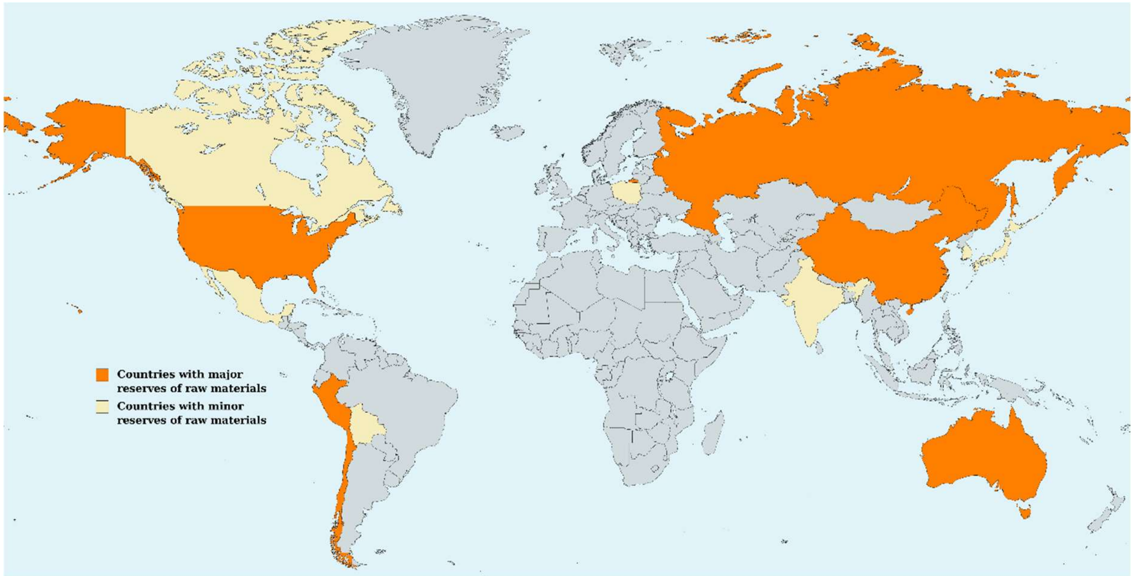

Figure 4. Countries with the reserves of raw materials for solar cell fabrication.

Offshore wind power generates electricity using wind farms constructed in water body usually sea. These wind farms do not require a large land but their construction and maintenance cost are significantly higher as compared to the onshore farm. In wind farms, mechanical energy of wind is converted to the electrical power using wind turbines and electric generators [24]. Wind energy has tremendous potential and according to an estimate the total amount of economically extractable power from the wind is more than what the world uses from all sources. Various models support this claim via top-down and bottom-up approaches. Using top-down" calculation, Kleidon [25,26] has shown that 18-68 TW power could be extracted from wind energy. Archer and Jacobson [27] did calculation using "bottom-up" approach and estimated that 72-170 TW power could be extracted practically. However, a recent study by Miller [28] does not support this claim and says that the estimates are too high by a factor of about 4. Wind energy has evolved a lot since its inception in 1982 and the kind of growth and potential it has shown is exceptional [29]. In 2019, wind contributed ~2% of the global energy demand [30].

India ranks fourth among world in terms of wind energy installations with an installed capacity of ~42 GW [12]. The Government is promoting wind power projects through private sector investment by providing various fiscal and financial incentives. Like solar energy, wind power also has certain drawback that needs to be overcome to utilize its power fully. Wind power is not a steady power source and varies greatly with geography and time. Therefore, it cannot meet the demand at all times and must be used with other power sources to ensure a reliable supply [31]. Capacity factor for wind energy is calculated (Supplementary Sheet 3, SI) for last 7 years in India and the value range between 12-20% which suggests that like solar energy wind is also an intermittent energy source that needs to be stored. In India wind has attain a steady growth as already shown in Figure 2. The development of wind power in India began in the 1990s, and has significantly increased in the last few years. By current estimation [12] the overall potential for wind power in India is 302 GW at 100 m height and 2% land availability out of which 42 GW is already installed in 2022 that measures ~10% of the total electricity generated in India. Although the estimates for wind potential have increased a lot in past several years because of exploration of new sites; for prediction let us take the current estimates and look at the energy requirement in India and numbers suggested by other researchers. Consumption of overall energy in India's electricity sector was ~18.2% in 2021. This suggests that apart from the electricity sector a large amount of energy is consumed in India. Considering the maximum potential of wind energy, it can contribute ~ 75% at max in the overall installed power at 2021 level which means that the wind energy potential in India's energy demand is limited. Veers et. al. [32] have already mentioned that to extract reasonable amount of energy from wind, a large gap still exist that has to be complemented by aggressive research and policy decisions. Now let us look at the materials needed to convert wind energy into electricity.

Primary raw material in a wind turbine is steel (60% to 71%), cast iron (12% to 16%), fiber glass, and epoxy (11%) and glass/ceramic (6%), tool steel (6%), stainless steel (3%), aluminum (1% to 4%), and copper (0.7% to 2%). India has reserves for these elements. Rare earths elements neodymium, praseodymium, dysprosium and terbium are used to manufacture neodymium–iron–boron (NdFeB) permanent magnets. These magnets are used as components in generators for wind turbines. These elements are mostly concentrated in China [33]. In 2019, 67% of these oxides are produced in China while only 1% is produced in India. Interestingly China is also the biggest consumer of rare earth oxides with ~70-75% consumption. The importance of these elements can be seen by a whopping 243% and 103% increase in the price of neodymium and dysprosium respectively from 2020 to 2022. A detailed analysis of mineral availability for wind energy in India has been given by Verma et. al. [34] The reserve of rare earth elements in different part of the world is depicted in Figure 5.

Next we move on to the batteries. As mentioned that because of the intermittent nature of solar and wind energy strong batteries are needed to store them. In this context energy density of a battery is an important parameter that states the amount of energy stored within a given volume or weight. Most of the storage batteries use Li ion and for the best Li ion batteries the energy density is in the range of 150-300 Wh/Kg [35,36]. Considering India's overall energy requirement, the amount of Li needed only to store the solar and wind energy will be ~10^{12} kg considering 100% storage [37] (Supplementary Sheet 4, SI) and the business as usual scenario. Energy efficiency of various processes increases upon electrification and Jacobson et. al. [10] have shown that the energy requirement of India can be decreased by 50% if all the processes are electrified by 2050. Considering this scenario and only storage the Li requirement will be ~10^{11} kg. The total Li reserves in world are estimated to be ~21 X 10^9 kg in 2020 [38]. Although new reserves are being explored continuously to meet the global Li demand and ~80 X 10^9 kg of potential resources are identified in 2020

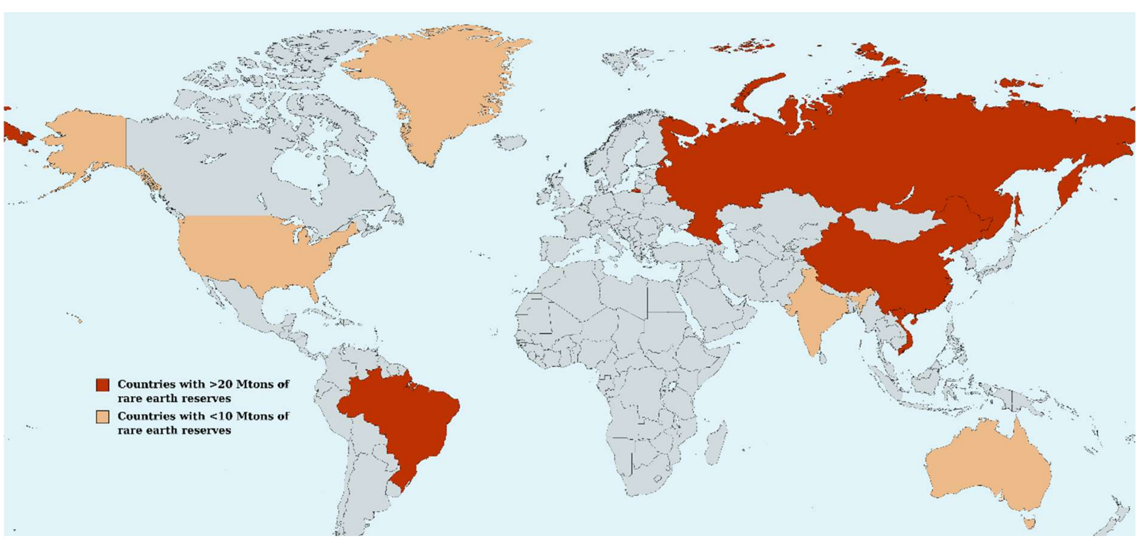

Figure 5. Countries with reserves of rare earth elements for wind energy harvesting.

[38]. This suggests that the total Li requirement to meet the solar and wind energy storage requirement is close to total terrestrial Li reserves. Because of high demand of Li, its prices have been increased 3.5 times in last 5 years [39]. India has very less reserve of Li; ~1600 tons which was discovered last year only in Mandya, Karnataka. A huge deposit of ~5.9 million tons of Li has also been found very recently in Jammu and Kashmir.

3. Sustainable waste management plan: After the implementation of any technology it is essential to assess the waste generated out of it and opt for the necessary measures to protect the environment. Since solar cell uses enormous amount of material, it implies that a huge amount of waste may be generated. The efficiency of a solar module deteriorates with time because of induced heat and humidity. These processes generate defects in the material that ultimately decrease the performance of the solar module and therefore needs to be replaced. In general, the lifetime of a solar module is expected to be ~25-40 years before the nominal efficiency drops by 20% [40,41]. IRENA has carried out a study to estimate the waste generated for different countries from the solar panel. For India they have estimated that it will generate ~600 GW from solar from which ~4.5 million tons of waste will be generated in 2050 considering the regular loss scenario and 30 years span lifetime of solar module [40]. However, a recent Harvard study review suggests that this amount can be 50 times more [42]. Presently, most of the countries do not recycle this waste except EU because of high cost involved ~15$ and bury it in landfills that cost ~1-2$ for one solar panel [42]. However, considering future scenario processes needs to be developed to recycle this waste and extract useful materials out of it because of large amount of waste and corresponding land requirement.

Like solar energy, wind energy also generates a huge amount of waste. Tazi et. al. [43] have carried out a study on the waste generated from wind industry in France Champagne-Ardenne (CA) region. This region has a total installed capacity of 181 GW. They have estimated that ~1 million ton of waste will be generated between 2002 to 2020 from this region majority of which includes ferrous and non-ferrous metals, polymers, glass and concrete. This is a huge waste amount to handle. Most of this waste is non-recyclable and goes into landfills and India needs to think about this waste disposal because of limited land availability.

Both solar and wind energy industries also generate waste from the storage battery. Over a period of time much work has been done with storage battery waste and reuse, refabricate and refurbish practice is prioritized. The battery material from electric vehicle is used in storage batteries and then after treatment and extraction of valuable components it is released as a waste. China is pioneer in this work and by 2019 it was reported that 58% of Li ion batteries have been recycled [37].

Let us compare this waste amount to the waste generated from well established nuclear industry. By an estimation there is ~0.265 million tonnes of heavy metal of spent fuel in storage worldwide in 2016 out of which 127 000 tons has already been reprocessed [44]. This number represents the contribution from ~95% of nuclear power installation worldwide with an overall capacity of 384 GW [44]. Taking into account the capacity factor for nuclear (~80%) this value comes around 2691.072 TWh/Y. If we compare this to predicted electricity generated by solar taking 20% capacity factor into account, the value is 1051.2 TWh/Y. Therefore, the electricity produced by the nuclear in the world today is almost 2.5 times the value predicted for India by solar in 2050 however the waste generated from solar alone in India is 20 times more as compared from all nuclear installation. This shows that solar industry will generate a huge waste and actions needs to be taken to handle this waste. Here we would also like to mention that India follows close fuel cycle operation where reprocessing of fuel is done to recover the useful materials with application in other industries and make ‘wealth from waste’ [44]. Also the average operating life of nuclear reactors is ~60 years. As of 2020, ~66% of the global nuclear power plants have operated for >31 years and ~ 20% have operated for >41 years [44]. It is already recognized as one of the most reliable and clean technology for base load power generation. This can be seen by looking at the mortality rate from various energy producing industries and compare it with nuclear technology. In 2012, the global mortality rate (deaths/ billion kWh) was only 0.04% for nuclear while for solar and wind it was 0.44 and 0.15% respectively. This is against the global electricity production of ~17% from the former as compared to ~1% each from the later industries. In spite of many advantages its expansion is not at par the rate needed. One of the major problems with nuclear energy expansion is public acceptability and radiation fear because of the Linear no threshold model (LNT). Although many researchers have carried out studies to oppose this model [45–47] still the policies are not being reframed to make nuclear energy as the fuel of the future. However, the Indian government is now planning to install Small Modular Reactors (SMRs) along with rapid solar and wind energy expansion to meet the India's target for clean energy and achieving net zero emission by 2070.

4. Conclusions: Greenhouse gas emissions, resource availability, waste generation and space requirement are major factors that decide the merits of an energy source. India particularly has enormous potential for solar and wind energy, but has poor reserves of materials needed because of which it is heavily dependent on the imports from other countries. This problem needs to be solved by design and production of new innovative material and favourable technologies so that the possibility of self reliant technology can be realized. Moreover these energy sources are intermittent in nature and generate huge amount of waste for which no measures has been taken yet. In our opinion researchers have over predicted the growth of solar and wind energy in India without taking into consideration other important factors and to sustain the energy need and meet the 2070 criteria of net zero emission nuclear energy expansion at a larger scale is needed along with other renewable energy sources.

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SUPPLIMETARY INFORMATION

Figure SF1A and SF1B and Supplementary Sheets 1-4**.**

Notes

The authors declare no competing financial interest.

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Supplementary Information

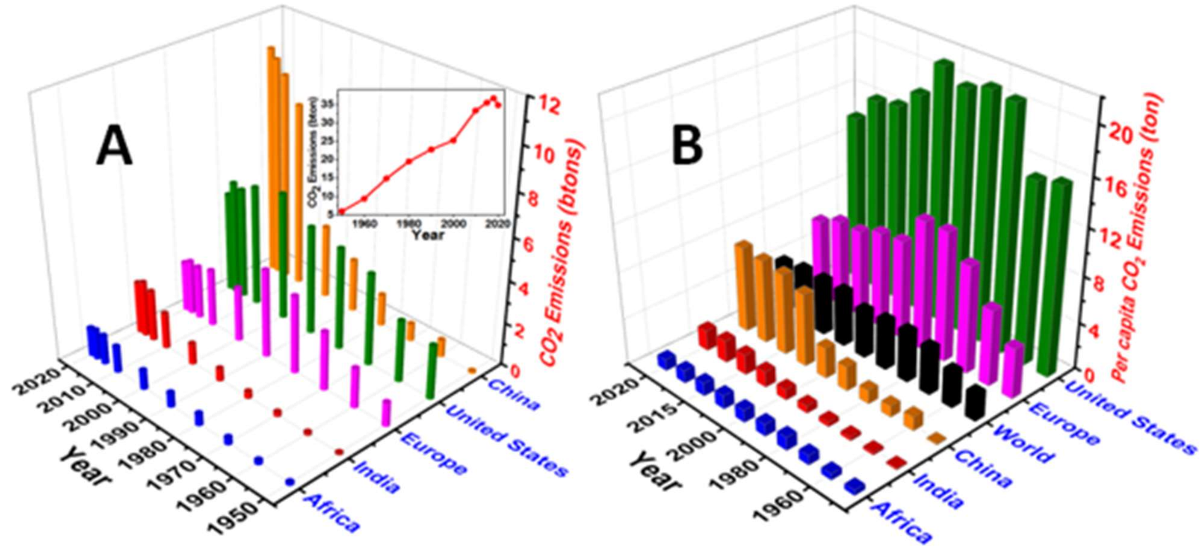

Figure SF1A: Annual CO_2 emission and SF1B: Per Capita CO_2 emission by fossil fuel for various countries at different time period.

Supplementary Sheets

Sheet 1

Energy generation using solar and wind as per Liu prediction (TWh)	Increase Rate	Year	Wind Energy Generation considering 6.5% annual growth (TWh)	Solar Energy Generation considering 6.5% annual growth (TWh)
1078.42871	0.065	2020		
1148.526576	0.065	2021	62	
1223.180803	0.065	2022	66.03	89.814
1302.687556	0.065	2023	70.32195	95.65191
1387.362247	0.065	2024	74.89287675	101.8692842
1477.540793	0.065	2025	79.76091374	108.4907876
1573.580944	0.065	2026	84.94537313	115.5426888
1675.863706	0.065	2027	90.46682239	123.0529636
1784.794847	0.065	2028	96.34716584	131.0514062
1900.806512	0.065	2029	102.6097316	139.5697476
2024.358935	0.065	2030	109.2793642	148.6417812
2155.942266	0.065	2031	116.3825228	158.303497
2296.078513	0.065	2032	123.9473868	168.5932243
2445.323616	0.065	2033	132.003967	179.5517839
2604.269651	0.065	2034	140.5842248	191.2226498
2773.547179	0.065	2035	149.7221994	203.6521221
2953.827745	0.065	2036	159.4541424	216.88951
3145.826549	0.065	2037	169.8186617	230.9873282
3350.305275	0.065	2038	180.8568747	246.0015045
3568.075117	0.065	2039	192.6125715	261.9916023
3800	0.065	2040	205.1323887	279.0210564
			Total in 2040 = 484.15 TWh	

Sheet 2

Year	Wind Power (MW)	% Increase	Solar Power (MW)	% Increase	Total Power (MW)	% of Solar Power in Total Output	% of Wind Power in Total Output	Total energy generated by Solar in electricity sector (GWh/Y)	Total energy generated by Wind in electricicty sector (GWh/Y)	Total energy consumption in electricicty sector (GWh/Y)	% of Solar energy generated in total enegy consumption in electricity sector	% of wind energy generated in total enegy consumption in electricity sector
2012	18,421									10,56,838		
2013	20,150	9.4	2,319							11,08,498		
2014	22,465	11.5	2,632	13				3,350		11,77,810	0.284426181	
2015	23,447	4.4	3,744	42				4,600	28,214	12,71,872	0.361671615	2.218304987
2016	26,777	14.2	6,763	81				7,450	28,604	13,51,970	0.55104773	2.11572742
2017	32,280	20.6	12,289	82	3,26,841	3.759932199	9.876361901	12,086	46,011	14,33,392	0.843174791	3.209938384
2018	34,046	5.5	21,651	76	3,44,002	6.293858757	9.897035482	25,871	52,666	14,86,493	1.740405101	3.54296993
2019	35,626	4.6	28,181	30	3,56,100	7.913788262	10.00449312	39,268	62,036	15,46,517	2.539125014	4.011336442
2020	37,669	5.7	34,627	23	3,70,106	9.35596829	10.17789498	50,103	64,639	16,22,983	3.087093334	3.9827281
2021	38,785	3.0	40,085	16	3,82,151	10.4893092	10.14912953	60,402	60,150	15,73,187	3.839467272	3.823448833
2022	40,355	4.0	56,951	42	3,99,497	14.25567651	10.10145258					

Sheet 3

Year	Installed Capacity Solar Energy (MW)	Energy generated from Solar (GWh/Y)	Solar Capacity Factor	Installed Capacity Wind Energy (MW)	Energy generated from Wind (GWh/Y)	Wind Capacity Factor
2013	2,319					
2014	2,632	3,350	14.53			
2015	3,744	4,600	14.00	23,447	28,214	13.73
2016	6,763	7,450	12.57	26,777	28,604	12.19
2017	12,289	12,086	11.22	32,280	46,011	16.27
2018	21,651	25,871	13.64	34,046	52,666	17.66
2019	28,181	39,268	15.90	35,626	62,036	19.87
2020	34,627	50,103	16.51	37,669	64,639	19.59
2021	40,085	60,402	17.20	38,785	60,150	17.70

Sheet 4

Energy consupmtion (QUAD) INDIA	Energy consumption (kWh)	Material weight needed for Li ion battery (kg)	Amount of Li ion needed (kg)	Uranium needed (kg)
12.12	3.55E+12	1.18E+13	1.60E+11	4.28E+05
17.48	5.12E+12	1.71E+13	2.31E+11	6.17E+05
22	6.45E+12	2.15E+13	2.91E+11	7.77E+05
36.48	1.07E+13	3.56E+13	4.83E+11	1.29E+06
58	1.70E+13	5.67E+13	7.67E+11	2.05E+06
82	2.40E+13	8.01E+13	1.08E+12	2.90E+06
120	3.52E+13	1.17E+14	1.59E+12	4.24E+06