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The Role of Renewable Energy in Mitigating Climate Change: A Case Study of India's Transition to a Sustainable Energy Future.

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Abstract

The rapid growth of human population and industrialization, particularly since the Industrial Revolution, has significantly contributed to global climate change, primarily through the increased use of fossil fuels and the rise in greenhouse gas (GHG) emissions. As the third-largest emitter of GHGs, India faces a critical challenge in balancing its economic development with environmental sustainability. This paper explores India's transition to renewable energy as a strategic response to mitigate climate change while addressing energy security, economic growth, and environmental concerns. Focusing on the period from 1990 to 2023, this research investigates the relationship between fossil fuel consumption, global warming, and the increasing demand for renewable energy. The paper highlights key factors driving India's renewable energy push, including climate change commitments, energy security, and the rising potential of solar and wind energy. Statistical analysis of fossil fuel consumption trends, sectoral GHG emissions, and India's renewable energy adoption underscores the urgency of reducing dependence on coal, oil, and gas.

Keywords:- Green House Gas Emissions, Energy Consumption, Renewable & Non-Renewable Energy Resources.

Introduction

Humans (Homo sapiens) are indeed considered the most intellectually advanced species on Earth as compared to other species (including those which extinct over time). Humans over the period have developed complex cognitive skills which include advanced reasoning, problem-solving, abstract thinking, cultural transmission, learning, innovation, and the capacity for language allowing rapid adaptation to changing environments. Because of these traits, humans are able to build civilizations, develop technology, and dominate ecosystems. and are experiencing rapid population growth. The human population has grown exponentially over the last few centuries, especially with improvements in agriculture, healthcare, and technology. It took over 1,00,000 years for the global human population to reach 1 billion in the early 19th century and about 220 years to surpass 8 billion in 2022. This population growth is expected to reach 10 billion people by 2060.

This growing population around the world has a deeper impact on the resources available and certainly, it impacts on climate more harshly. One of them would be the effect on global emissions. As the population grows more resources are required for human consumption purposes which will lead to an increase in resource availability followed by an increase in Greenhouse Gas levels, leading to rising temperatures.

Overview of the Relationship Between Energy Use and Climate Change:- The Industrial Revolution was a very crucial period that fundamentally altered the course of society, economy, and technology, from agrarian economies into capitalist, industrialized systems. The changes that occurred during this era were essential in

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shaping the modern world. Basically, it emerged in Great Britain in the late 18th century but later spread quickly to the United States, Western Europe, and other regions. The revolution was driven by the introduction of machinery, factories, and new manufacturing processes, leading to sweeping economic and social changes.

With population growth, industrialization, and increasing living standards, global energy demand has risen sharply. This has led to higher fossil fuel consumption and, consequently, increased GHG emissions.

Annual CO2 Emissions from the Beginning of Industrialization Era

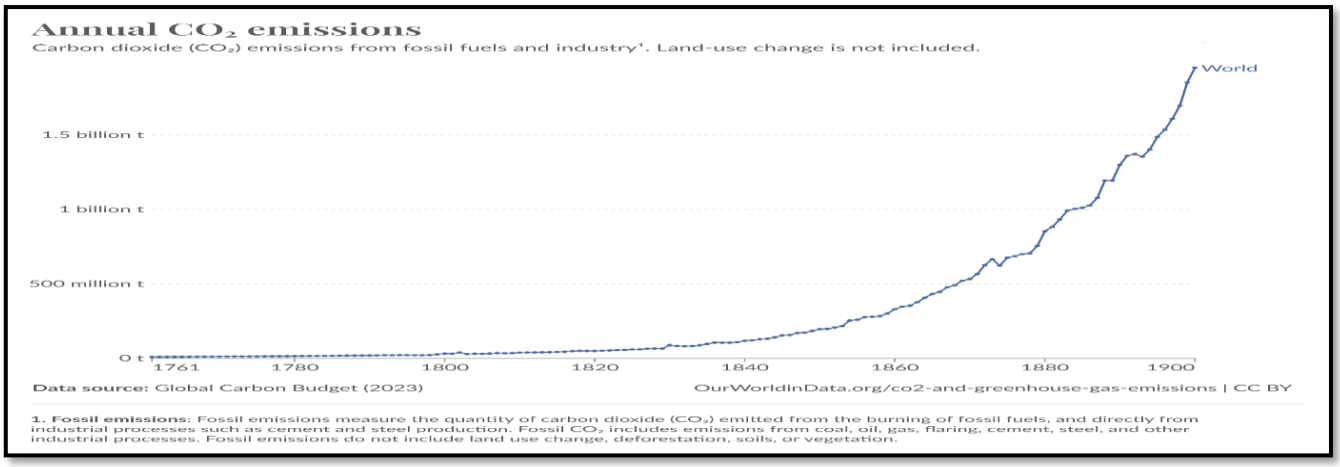

Figure: 1, Source: Our WorldinData.org

The figure (Figure:1) given above shows the impact of industrialization on climate. As the emergence of industrialization started during the late 18th century, Carbon Dioxide also known as CO_2 emissions (which occurs basically from the burning of fossil fuels and other non-renewable resources) looks almost stagnant. After 1800 it started taking pace and from 1840 onwards, we see an exponential increase in CO_2 emissions. It took around 108 years to reach from 0 (zero) to 500 million tonnes of CO_2 emission and another 16 years to double the figure by reaching 1 billion tonnes of CO_2 emission. Next 11 years it reach 1.5 billion tonnes of CO_2 emissions and in just the next 5 years to reach almost 2 billion tonnes of CO_2 emissions. It is a matter of great concern as this shows the pace with which human beings are contributing to global warming in totality, causing dangerous and widespread disruption in nature and affecting the lives of billions of people around the world.

India's Need for Renewable Energy to Combat Climate Change:- The demand for renewable energy in India to deal with the issues of climate change is important because of its huge population and rapid urbanization. As one of the major contributors of greenhouse gases in the world due to its dependence on coal for electricity, India needs to shift towards renewable energy to achieve its climate targets, be energy self-sufficient, and promote development that is almost environmentally neutral.

Key Reasons for India's Renewable Energy Push:

Climate Change Commitments: In the framework of the Paris Agreement, India's non-fossil fuel share targets as well as the targets for the reduction of its carbon emissions have been reasonably ambitious; for example, India targets 50% of its energy from non-fossil fuel sources by 2030 and aims to reduce its carbon intensity (emissions per unit of GDP) by 45% in comparison to 2005 levels. Such targets are important in the context of a temperature increase globally which it is necessary to combat the consequences of climate change.

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Energy Security: The Indian economy uses oil and coal in the areas of energy and other industries - both of which constitute a major proportion of energy imports for India. Such dependence not only affects the economy adversely but also exposes India to threats arising from international markets and geopolitical threats. Renewable energy, in the form of solar and wind, which are in abundance in the country, can have a lot of impact on the energy needs of the country in a sustainable, stable, and secure manner. Harnessing these resources can improve India's self-sufficiency in terms of imports.

Health and Environmental Concern: Air pollution happens to be one of the key issues in an average Indian's health affecting people's lives indeed, and the coal-fired power plants rightly rank among the highest contributors. The combustion of fossil fuels emits numerous toxic gases, including sulphur dioxide (SO2) and nitrogen dioxide (NO2) which lead to various diseases and result in early deaths. Shifting to clean energy will reduce carbon emissions tenfold.

Reducing Fossil Fuel Reliance: India still relies heavily on coal, which contributed over 70% of the country's electricity generation in 2022. While coal has been one of the cheaper energy sources to have, it appears that its environmental and social costs are becoming unmanageable. Cleaner alternatives like solar, wind, hydro, and bioenergy are possible and quickly becoming cheaper than fossil fuels, and are thus more viable alternatives.

Solar Energy Potential: India has over 300 days of sunshine in most parts and thus one of the highest solar potentials in the world. The government has undertaken key projects including the National Solar Mission which has a target of 100 GW solar capacity by 2022 (However, as of early 2023, India had reached about 64 GW). This ambitious plan also includes establishment of large-scale solar parks and provisions of decentralized solar in rural areas.

Decentralized Renewable Energy for Rural Areas: Furthermore, localization of renewable energy is important here as there are still about 200 million people in India who do not have access to regular electricity, particularly in India's remote rural region. Cost-effective and environmentally friendly off-grid and localized solar, mini-grids, and bioenergy technologies can be implemented to provide sustainable and affordable energy which can change the quality of life, education, and economic activities in those areas.

Impact of Fossil Fuel-Based Energy Production on Global Warming.

Table Showing Major Components of Fossil Fuels in India (1990-2023)

Year	Oil consumption - TWh	Gas consumption - TWh	Coal consumption - TWh
1990	694.05817	115.927345	1276.025
1991	706.101	129.10802	1357.8776
1992	744.1866	144.3469	1438.2565
1993	752.0428	146.67085	1489.6254
1994	808.2667	158.56918	1537.2871
1995	901.3517	180.77829	1631.6134
1996	972.76135	197.31721	1678.4825
1997	1039.8557	214.52634	1755.3625
1998	1113.5074	235.42874	1813.659
1999	1219.4528	241.23369	1796.674
2000	1277.5098	253.62692	1911.1661

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2001	1281.0958	254.27748	1926.9531
2002	1324.2423	265.54413	2012.7899
2003	1347.6937	284.26898	2107.9834
2004	1426.8563	306.69138	2243.5286
2005	1450.1283	343.25635	2456.1133
2006	1532.0393	358.77188	2549.8647
2007	1637.4816	388.1026	2790.2725
2008	1719.2587	399.87665	3020.762
2009	1806.7904	491.08084	3268.2656
2010	1848.4161	589.6162	3348.546
2011	1935.7648	602.85876	3478.864
2012	2051.6697	556.9909	3787.818
2013	2065.6555	490.193	4009.7288
2014	2125.4941	485.01566	4401.073
2015	2296.0383	478.0684	4490.47
2016	2514.2617	507.90982	4587.692
2017	2588.196	535.9986	4737.1567
2018	2704.5122	579.96277	4981.6016
2019	2791.946	592.4984	4989.023
2020	2537.8525	603.6012	4714.672
2021	2588.8313	623.72705	5352.792
2022	2804.53	582.5085	5562.6577
2023	2936.9744	626.1031	6105.902

Table:1, Source: Our WorldinData.Org

Descriptive Statistics:

Oil:

Minimum Value: 694.1 TWh (1990)

Maximum Value: 2937.0 TWh (2023)

Overall Percentage Growth: 323%

Mean: 1692.5 TWh per year, reflecting moderate usage compared to coal.

Range: A significant difference between the minimum (694.1 TWh) and maximum (2937 TWh), showing substantial variability in oil consumption over the years.

Skewness and Kurtosis: A near-zero skewness (0) and a negative kurtosis (-1.2) indicate that the data is relatively symmetrically distributed with lighter tails than a normal distribution.

Standard Deviation: 703.88 TWh, suggesting considerable year-to-year fluctuations in oil consumption.

Gas:

Minimum Value: 115.93 TWh (1990)

Maximum Value: 626.10 TWh (2023)

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Overall Percentage Growth: 440%

Mean: 381.3 TWh per year, the lowest among the three energy sources.

Range: 510.2 TWh, showing that gas consumption has been much more consistent compared to oil and coal.

Skewness and Kurtosis: Skewness is close to zero (-0.017), indicating a near-symmetric distribution, while a kurtosis of -1.55 suggests a flatter distribution compared to a normal one.

Standard Deviation: 174.15 TWh, indicating moderate variability in gas consumption over time.

Coal:

Minimum Value: 1276.0 TWh (1990)

Maximum Value: 6105.9 TWh (2023)

Overall Percentage Growth: 379%

Mean: 3076.8 TWh per year, the highest among the three energy sources, signifying its importance in energy production.

Range: The range of 4829.9 TWh reflects the vast variation in coal consumption over time, with the minimum of 1276 TWh and the maximum of 6105.9 TWh.

Skewness and Kurtosis: The positive skewness (0.484) and a slightly negative kurtosis (-1.15) indicate a longer right tail, suggesting some years with significantly higher consumption.

Standard Deviation: 1455.7 TWh, the highest standard deviation, points to the large year-to-year variations in coal consumption.

Coal has been the dominant energy source with the largest consumption but also the highest variability and peaks, reflecting its importance in energy production, albeit with volatility.

Oil consumption, though significant, has shown large variations but with slightly more stability compared to coal.

Gas has had the most consistent consumption, with relatively lower variability, indicating it as a steady energy source over the 34 years examined.

Consumption in Tera Watt Hours of Fossil Fuels in India

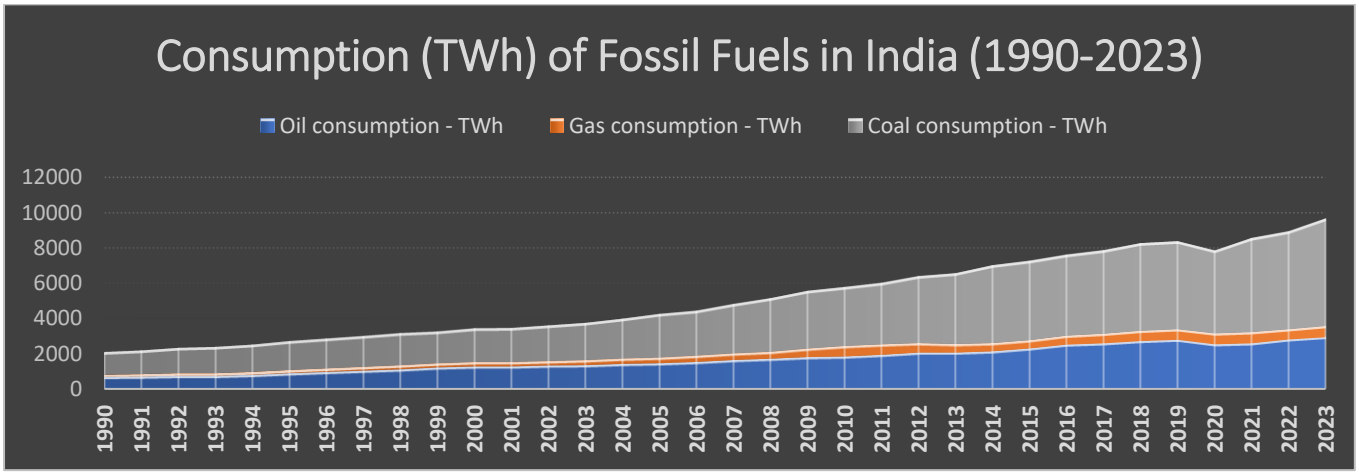

Figure: 2, Source: Author's Contribution

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Green House Gas Emissions by Major Sectors in India

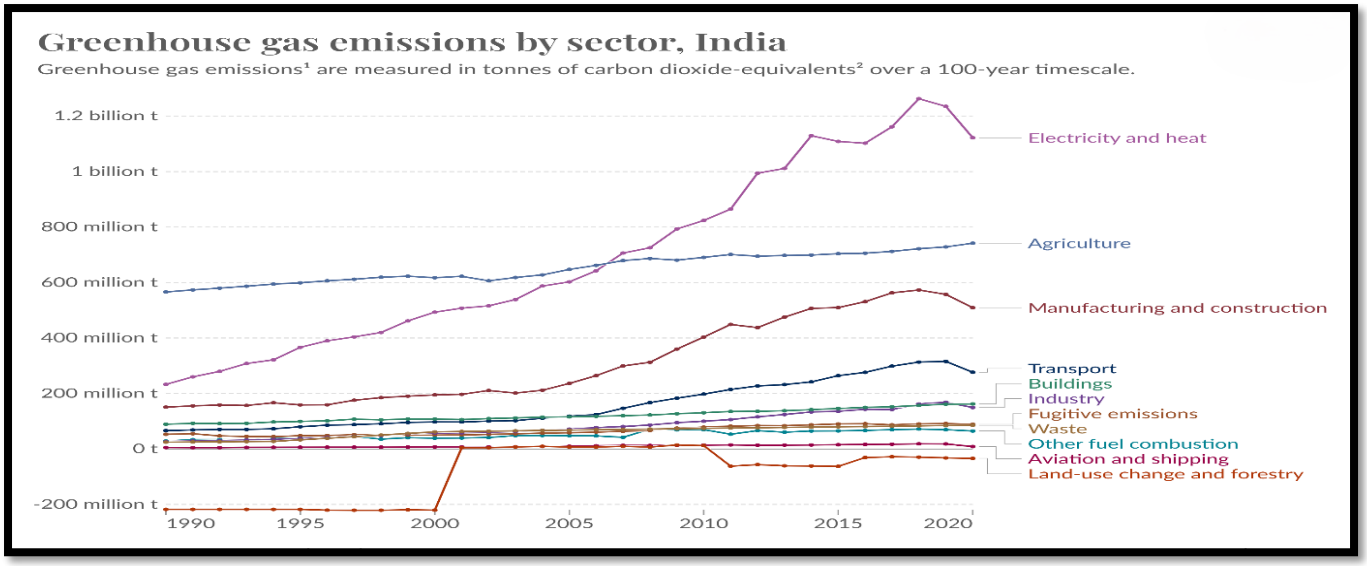

Figure: 3, Source: Our WorldinData.Org

Table Showing Compounded Average Growth Rate of Green House Gas Emissions (1990-2020)

S.No.	Sectors	GHG Emission	CAGR	Overall %Growth
1	Electricity & Heat (1990)	232960000	5%	382%
	Electricity & Heat (2020)	1121980000		
2	Agriculture (1990)	566020030	1%	31%
	Agriculture (2020)	741920000		
3	Manufacturing & Construction (1990)	151060000	4%	237%
	Manufacturing & Construction (2020)	509450020		
4	Transport (1990)	66019996	5%	319%
	Transport (2020)	276440000		
5	Buildings (1990)	89370000	2%	82%
	Buildings (2020)	162490000		
6	Industry (1990)	26450000	6%	465%
	Industry (2020)	149370000		
7	Fugitive Emissions (1990)	52870000	2%	68%
	Fugitive Emissions (2020)	88990000		
8	Waste (1990)	24540000	4%	248%
	Waste (2020)	85350000		
9	Other Fuel Combustion (1990)	28690000	3%	126%
	Other Fuel Combustion (2020)	64830000		
10	Aviation & Shipping (1990)	5160000	2%	73%
	Aviation & Shipping (2020)	8920000		
11	Land-use Change & Forestry (1990)	-217850000	-6%	-84%
	Land-use Change & Forestry (2020)	-33870000		

Table: 2, Source: Author's Contribution

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The table 2 outlines greenhouse gas (GHG) emissions across various sectors from 1990 to 2020, providing data on compound annual growth rate (CAGR) and overall percentage growth.

The table highlights the dramatic increase in GHG emissions across most sectors, particularly in Industry (465%), Transportation (319%), and, Electricity & Heat (382%) (energy production), over the past 30 years. However, it also shows positive trends in sectors like **Land-use Change & Forestry (-84%)**, which have improved their capacity to reduce overall emissions by absorbing carbon. It also highlights the importance of targeted efforts in sectors where emissions are rapidly growing while maintaining and expanding carbon sinks in land-use sectors.

Greenhouse Gas Emissions and their Effect on India's Climate Patterns:

Increase In Temperature: The temperature of India has altered with an average increase of 0.7 from 1901-2018, which is however estimated to be between 1.5 to 2 degrees by the middle of the century. This shows the occurrence of more heat waves, aggravating health impacts as well as increased energy demand, amongst others.

Change in Monsoon Seasons: Climate change has led to changes in the monsoons making the rains unpredictable. This means that too much rain in some seasons causes floods and little rainfall in some seasons areas leads to droughts causing the threat of water and food insecurity.

Glaciers Melting & Sea Level Rise: The number of Himalayan glaciers has been decreasing at a rapid pace resulting in issues with freshwater supply. The rise of sea level on the other hand has led to the flooding of places such as Mumbai, Kolkata, and many other cities located closer to the edges of the sea.

Flooding and Other Issues pertaining to Weather Factors: The increase in the frequency of cyclones, floods, and droughts have severely affected social infrastructure and in extreme cases even led to the displacement of people from their homes resulting in further economic instability.

Food Security and The Agriculture Sector: The current climate change patterns are causing a decline in food production, fear of famine, and overall increasing poverty levels, especially in rural communities furthering existing socio-economic issues**.**

Water Availability: There are growing tensions across the country about water access due to rainfall being irregular and the glacial melt being insufficient regarding water sources in North Indian states and the Himalayas.

India's Energy Transition:

Table Showing Overview of India's Energy Consumption Patterns (1990-2023).

	Renewable Energy Consumption (TWh)					Non-Renewable Energy Consumption (TWh)			
Year	Wind	Hydro	Solar	Biofuels	Other renewables	Coal	Oil	Gas	Nuclear
1990	0.089606	196.3354	0	0	0.119983	1276.025	694.0582	115.9273	18.14554
1991	0.333874	218.5774	0	0	0.303487	1357.878	706.1010	129.1080	15.36164
1992	0.261605	207.1689	0	0	0.381123	1438.257	744.1866	144.3469	18.17062
1993	0.280234	209.1552	0	0	0.804594	1489.625	752.0428	146.6709	17.66902
1994	0.565613	237.1863	0	0	1.213948	1537.287	808.2667	158.5692	14.03239
1995	1.468056	224.4972	0.002987	0	1.799749	1631.613	901.3517	180.7783	21.60662
1996	2.597360	204.2024	0.017921	0	2.413781	1678.483	972.7614	197.3172	23.83876
1997	2.921505	207.6132	0.017921	0	3.133681	1755.363	1039.856	214.5263	28.57892

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1998	3.190591	247.3011	0.017921	0	4.126013	1813.659	1113.507	235.4287	32.26571
1999	4.275806	243.2107	0.017921	0	5.382308	1796.674	1219.453	241.2337	36.11552
2000	4.677957	227.6597	0.020908	0.614167	5.382308	1911.166	1277.51	253.6269	44.74312
2001	6.125288	211.5882	0.032642	0.947306	6.605149	1926.953	1281.096	254.2775	53.24842
2002	6.085770	200.0712	0.038328	1.001278	6.831000	2012.790	1324.242	265.5441	54.2046
2003	7.553315	200.9675	0.046871	1.049667	8.658980	2107.983	1347.694	284.2690	50.48722
2004	15.05787	289.9979	0.052394	1.109222	10.58012	2243.529	1426.856	306.6914	58.77755
2005	17.15471	278.9537	0.052062	1.168778	12.88098	2456.113	1450.128	343.2564	48.70884
2006	26.56840	320.4419	0.020487	1.182428	17.83485	2549.865	1532.039	358.7719	48.14245
2007	33.03453	346.7034	0.166830	1.182428	23.63189	2790.273	1637.482	388.1026	48.38428
2008	40.40358	323.6316	0.177034	1.655399	29.69388	3020.762	1719.259	399.8767	41.06998
2009	45.44022	296.9715	0.209453	0.865522	37.16364	3268.266	1806.79	491.0808	45.06526
2010	54.00277	301.8278	0.313640	1.493419	45.63256	3348.546	1848.416	589.6162	61.47768
2011	66.07612	363.3275	2.281407	3.191158	54.7048	3478.864	1935.765	602.8588	85.30224
2012	75.21842	317.4514	5.755323	2.946153	63.63978	3787.818	2051.67	556.9909	87.19555
2013	81.78270	359.7089	9.356360	3.428819	71.75436	4009.729	2065.656	490.1930	87.11104
2014	90.63260	376.5546	13.29896	2.992753	78.77083	4401.073	2125.494	485.0157	90.17042
2015	88.17162	358.9262	17.68308	3.591605	97.7368	4490.47	2296.038	478.0684	98.99297
2016	116.3245	343.6824	30.93579	7.590260	79.22082	4587.692	2514.262	507.9098	97.35407
2017	140.0618	361.4652	57.33638	5.467463	79.51202	4737.157	2588.196	535.9986	95.54765
2018	159.5672	369.7484	96.12273	10.54421	86.90485	4981.602	2704.512	579.9628	99.14305
2019	166.8946	427.2022	121.9604	12.99558	100.5914	4989.023	2791.946	592.4984	114.2381
2020	158.6998	429.9334	154.1198	12.18209	104.8811	4714.672	2537.853	603.6012	112.433
2021	178.1806	419.5526	178.7342	19.6767	113.3079	5352.792	2588.831	623.7271	110.2759
2022	182.6172	456.0803	248.0899	28.01564	123.1137	5562.658	2804.53	582.5085	115.5697
2023	213.2846	387.4861	294.5991	34.33682	119.0105	6105.902	2936.974	626.1031	120.1595
Total	**1989.600**	**10165.18**	**1231.479**	**159.2289**	**1397.723**	**104610.6**	**57544.82**	**12964.46**	**2093.587**
CAGR	**2559.771**	**0.681794**	**121390.2255**	**56.10561**	**1056.717**	**2.852775**	**2.470575**	**3.67637**	**5.065178**
Overall % Growth	**237,917.19%**	**97.34%**	**9,857,195%**	**5490.08%**	**98,758.33%**	**378.58%**	**323.13%**	**440.01%**	**562.30%**

Table: 3, Source: Author's Contribution

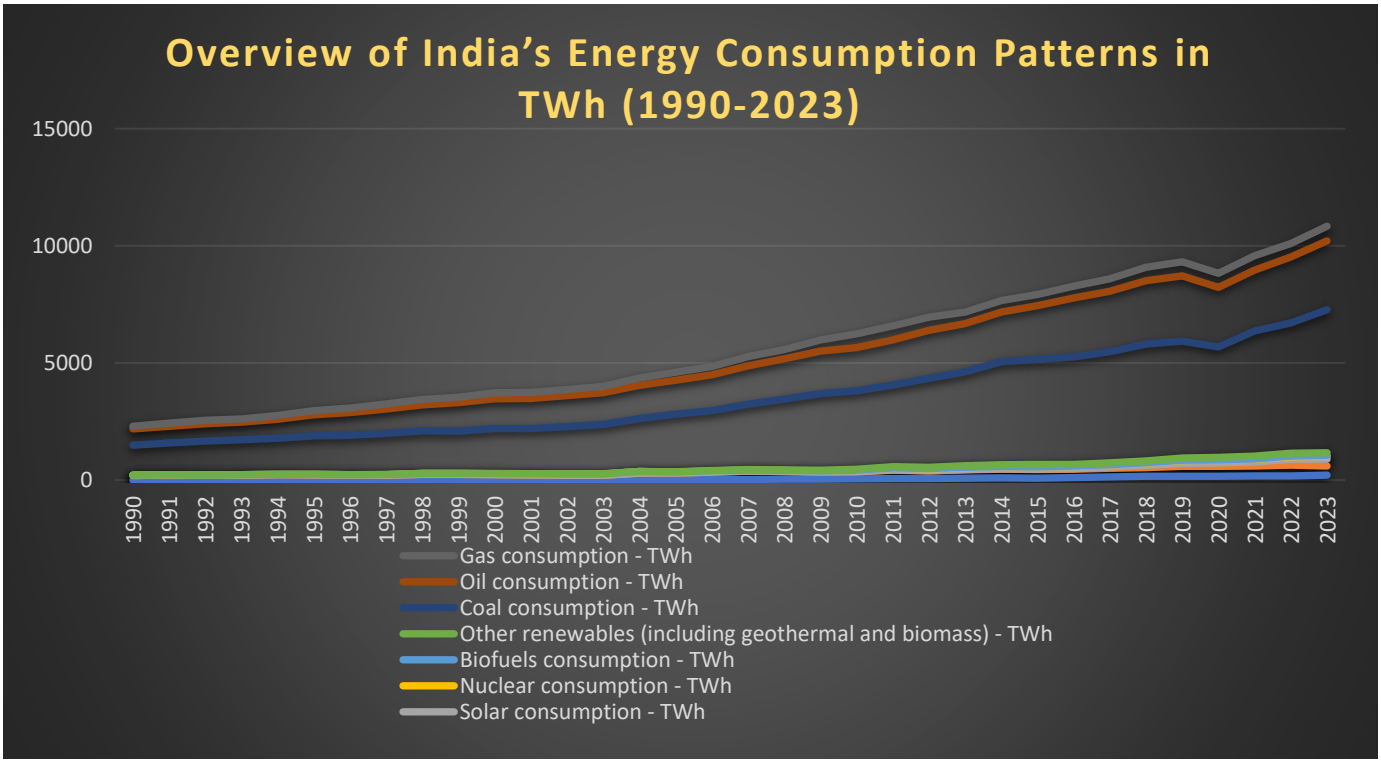

Figure: 4, Source: Author's Contribution

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The table above shows India's Energy Consumption Pattern from 1990 till date. This energy is broadly classified into renewable and non-renewable sources. Non-renewable energy resources (Coal, Oil, Gas, Nuclear) are those that are available in limited supplies, usually because they take a long time to replenish. The primary advantage of these non-renewable resources is that power plants use them and can produce more power on demand. On the other hand, renewable energy resources (Hydro, Solar, Biofuels, Geothermal, Biomass, and Wind) can refill themselves over the period, thus having an unlimited supply over the long haul.

While going through the last 34 years data it comes to the knowledge that Coal has been the dominating resource of energy supply under non-renewable supplies. Even the total of other (oil, gas, nuclear) supplies does not come near the individual consumption of coal alone in any single year. Thus, stood at the first position (totality-wise) followed by oil, gas, and lastly nuclear energy respectively. But, when we look from the CAGR (Compound Annual Growth Rate) point we can see a change though not large enough in numbers but still it holds importance from the shifting of energy consumption point of view, showing the commitment to a much better environmental control especially on CO_2 emission and Green House Gases. With a CAGR of 5.065178 for 1990 till 2023 Nuclear Consumption stood at first place followed by Gas with a CAGR of 3.67637, Coal 2.852775 and lastly Oil 2.470575 for second, third and fourth place respectively.

The overall percentage growth rate of renewable and non-renewable energy shows the transition phase of India's energy consumption pattern with a positive outlook on renewable energy resources. When we look at the table, we see that the total energy consumption of coal was the highest in terms of quantity of consumption among all followed by oil, gas, hydro, nuclear, wind, other renewables, solar, and lastly biofuels. But when it is seen from a percentage growth point of view an altogether different picture comes to light. The importance of solar energy in India though got its importance from 1995 onwards as compared to other resources in the study period but it comes out with the highest percentage growth of 9,857,195% followed by wind (237,917.19%), other renewables (98,758.33%), biofuels (5490.08%), nuclear (562.30%), gas (440.01%), coal (378.58%), oil (323.13%) and lastly hydro (97.34%). The first four spots are occupied by renewable energies and which is leading in quantity terms got the third last spot in terms of overall percentage growth. It is important to note that India is surrounded by water from three sides but the figures for the last 34 years do not show a very good picture of hydro energy consumption, showing underutilization of available resources.

India's Policies and Commitments Aimed at Reducing Emissions:

India as a party of the United Nations Framework Convention on Climate Change (UNFCCC) and its Paris Agreement, submitted its first pledge also known as National Determined Contribution (NDC) in 2015, because of extending cooperation to reduce Global Greenhouse Gas Emissions and controlling climate change by helping to limit global warming well below 2°C, preferably to 1.5°C, compared to pre-industry levels.

Out of the three primary targets given in NDC, India has achieved two targets well ahead of time. Those two targets were as follows:

i. To reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 level; and

ii. To achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.

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As on 31st October, 2023; the cumulative electric power installed capacity from non-fossil fuel-based energy resources is 186.46 MW, which is the 43.81% of the total cumulative electric power installed capacity. As per the third national communication submitted by India to the UNFCCC in December 2023, the emission intensity of its GDP has been reduced by 33 percent between 2005 and 2019.

In August 2022, India updated its NDC according to which target to reduce emissions intensity of its GDP has been enhanced to 45 percent by 2030 from 2005 level, and the target on cumulative electric power installed capacity from non-fossil fuel-based energy resources has been enhanced to 50% by 2030.

Conclusion:- India stands at a critical point where the dual challenges of economic development and environmental sustainability must be addressed with urgency. The country's heavy reliance on fossil fuels has not only contributed to its position as one of the top greenhouse gas emitters but has also exacerbated the impacts of climate change, including rising temperatures, erratic weather patterns, and stress on water resources. However, India's commitment to renewable energy offers a promising path forward, aligning with both its climate goals and its broader aspirations for sustainable growth.

This research underscores the importance of transitioning away from fossil fuels and highlights the growing significance of renewable energy, particularly solar and wind, in India's energy mix. The analysis of trends in fossil fuel consumption, sectoral emissions, and the expansion of renewable capacity demonstrates that India has made considerable progress, yet significant challenges remain. Achieving energy security, reducing emissions, and safeguarding public health will require further investments in renewable technologies, stronger policy frameworks, and a continued focus on decentralized energy systems.

India's renewable energy transition is not only an environmental necessity but also an economic opportunity. By embracing renewable energy, India can reduce its carbon footprint, enhance energy independence, and create new job opportunities in clean energy sectors. Moreover, the shift towards renewables can mitigate the adverse effects of climate change on agriculture, water security, and public health, all of which are crucial for the country's long-term resilience.

In conclusion, India's journey towards a sustainable energy future offers valuable lessons for other developing nations grappling with the same issues of climate change, energy security, and economic development. While the challenges are significant, India's renewable energy revolution holds the potential to create a cleaner, healthier, and more prosperous future, both for the country and for the world. To realize this potential, continued political will, technological innovation, and international cooperation will be essential in driving India's transition towards a low-carbon economy.

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