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India's Net Zero Journey: A Decade of Sustainable Progress - 2013 to 2023

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Abstract: ***The paper offers a thorough analysis of India's shift towards renewable energy sources, including the effects on carbon emissions and energy security. The research utilizes a comprehensive data collection approach, gathering data from many sources such as the Ministry of New and Renewable Energy (MNRE), Ministry of Power in India, International Renewable Energy Agency (IRENA), and the International Energy Agency (IEA), both at the national and international level. The analysis includes the use of quantitative and statistical approaches, evaluating energy security, conducting correlation analysis, forecasting time series, and performing comparison and variance analysis. Power BI is utilized for data manipulation and statistical modelling. The results demonstrate a steady rise in both the use and provision of electricity in India from 2014 to 2023, with a decreasing disparity between the amount needed and the amount available, projecting an excess by 2025. The expansion of renewable energy, including solar and wind power, has been strong and has made a considerable contribution to this change. The study's analysis of the energy mix from 2013 to 2022 shows that the portfolio of energy sources has remained constant but is steadily becoming more diverse, with renewable sources increasing their contribution. The research validates that the expansion of solar and wind energy capacity is linked to an increased proportion of renewable energy sources in India's energy composition, hence strengthening energy security. The budget analysis for the electricity industry and MNRE demonstrates a strong dedication to renewable energy, as evidenced by the progressively higher appropriations made over the years.***

Keywords: Renewable Energy Transition, Carbon Emissions Impact, Energy Security, Statistical Analysis, Net, Zero

1. Introduction

India, with its plentiful solar and wind energy resources, has emerged as a significant participant in the renewable energy sector in recent times (J. L. Holechek et al., 2022). According to IRENA (2023), India is now ranked fourth in worldwide renewable power capacity, demonstrating its commitment to increasing its solar and wind power resources. The country has set ambitious goals for renewable energy, aiming to have an installed capacity of 450 GW by 2030. This demonstrates the country's dedication to sustainable development and efforts to mitigate climate change (MNRE, 2023). This objective positions India as a leader and will contribute to the expansion of the worldwide renewable energy capacity, which is crucial for building the future low - carbon economy. India now lags behind leading countries like China and the USA in terms of overall capabilities. However, India's renewable energy installations are growing rapidly, suggesting that it would be able to close the gap in the next years (IEA, 2023).

2. Literature Review

The energy industry of India has seen significant changes, illustrating the journey of a growing nation towards sustainable development (A. K. Shukla et al., 2017). At the time of independence, India relied primarily on coal as its main energy source. However, throughout the years, the country has diversified its energy mix and demonstrated a consistent interest in exploring alternative energy sources. Citation: Kumar, C. R., & Majid, M. A. (2020)

Hydropower Development: The shift began with the development of hydropower, with large - scale hydroelectric projects marking the initial stage of India's energy revolution. India's policy and legislation regarding hydropower has consistently promoted its development. As a result, India now ranks as the fifth largest country in terms of its ability to generate usable hydropower. The reference is from a paper written by H. Nautiyal and colleagues in 2011.

The creation of the Bhabha Atomic Research Centre (BARC) in the 1950s was a major step towards India's goal of achieving energy self - sufficiency through nuclear power. Presently, India is the sole developing country that possesses domestically created, proven, and put into operation nuclear reactors for the purpose of generating power. This accomplishment has been attained over many years of meticulous scientific investigation and technological advancement.

Wind Energy: The investigation into wind energy in India commenced in the 1960s with the creation of windmills by the National Aeronautical Laboratory (NAL). India currently possesses the fourth - largest wind power capacity in the world, primarily because to its favorable geographical location that ensures a steady and reliable wind flow, especially in the Southern, Western, and North Western regions. The source of this information is a publication by S. Kumar in 1999.

Solar energy has significantly contributed to India's energy sector, offering a sustainable and environmentally friendly solution for millions of people's cooking, lighting, and other energy requirements (V. Khare, S. Nema, and P. Baredar,

2013). The successful utilization of solar energy in India has resulted in the establishment of the International Solar Alliance (ISA), a cooperative platform with the objective of facilitating the adoption of solar energy technologies. The International Solar Alliance (ISA) now has 107 signatories, all of which are members of the United Nations. (Holechek et al., 2022)

Biomass energy: Biomass energy, which is both renewable and readily available, has played a significant role in India's energy landscape. Technological advancements have led to increased efficiency in thermal power plants, resulting in reduced costs and energy consumption. This has made it feasible to implement biomass co - firing nationwide as a means to decrease CO2 emissions. (Kumar, A. et al., 2010)

India has been striving to sever the link between economic growth and the release of greenhouse gases, as part of its efforts towards clean energy and addressing climate change (Ch. M. S. Kumar et al., 2023). The Net Zero Emissions objective by Indian Railways and the UJALA LED bulb campaign are effective measures for mitigating emissions (M. Irfan et al., 2020). The National Hydrogen Mission, implemented in 2013, further bolsters India's efforts in promoting renewable energy. India, being the second most populated country in the world, has per capita CO2 emissions that are far below the worldwide average. The nation's adherence to a goal of attaining a 40% portion of electricity production from non - fossil fuel sources, which was accomplished ten years prior to the scheduled 2030 deadline, serves as evidence of its unwavering commitment to combatting climate change.

India's future goals encompass achieving Net Zero Emissions by 2070 and accomplishing short - term objectives such as raising renewables capacity to 500 GW by 2030, fulfilling 50% of energy needs from renewables, decreasing cumulative emissions by one billion tonnes by 2030, and reducing the emissions intensity of India's GDP by 45% by 2030. The India Renewable Integration Study, conducted by the Ministry of New & Renewable Energy

Government Policies and Initiatives towards net zero emissions:

India has implemented several policies to promote the adoption of electric vehicles, renewable energy, and energy efficiency:

The FAME plan aims to encourage the use of electric vehicles and the development of charging infrastructure to support the wider adoption and production of hybrid and electric vehicles. This information is outlined in the "Power Sector at a Glance All India, 2019" report. In addition to this, the NAPCC provides a detailed plan for tackling climate change by emphasizing solutions centered around solar energy, energy efficiency, sustainable agriculture, and afforestation (Agarwal, 2016). India has set a significant target of reaching a renewable energy capacity of 450 gigawatts (GW) by 2030. To achieve this goal, the Jawaharlal Nehru National Solar Mission and the Green Energy Corridors initiative, led by the Ministry of New & Renewable Energy, are working to accelerate the adoption of solar and wind energy sources across the country.

There are certain programs like Perform, Achieve, and Trade (PAT) and the National Mission for Enhanced Energy Efficiency (NMEEE) that focus on making industrial energy efficiency better. At the same time, the Bharat Stage VI (BS - VI) emission standards are in place to ensure that vehicle emissions are reduced by implementing strict regulations. It is crucial for the government, commercial sector, civil society, and citizens to collaborate effectively in order to drive India towards achieving net zero emissions. In 2021, India initiated the National Hydrogen Mission with the aim of becoming a prominent global supplier of hydrogen. The mission focuses on utilizing green hydrogen to decrease carbon dioxide emissions and address the issue of greenhouse effect.

By 2025, India has set ambitious goals for ethanol blending, with a target of achieving a 20% blending ratio of ethanol with petroleum. The promotion of electric vehicles through the FAME India initiatives is in line with NITI Aayog's goal of having electric vehicles make up 30% of all vehicles on Indian roads by 2030. This vision also includes a substantial increase in the use of electricity in industrial energy and aims for 70 - 80% of vehicles to be powered by electricity by 2070, in order to reduce vehicular pollution. The new car scrappage program aims to provide financial incentives to encourage people to replace their older, more environmentally harmful automobiles with electric or hybrid vehicles.

In addition, India places a high importance on the use of Carbon Capture and Storage (CCS) technology to capture greenhouse gases before they are released into the environment. Although CCS technology is currently expensive and complex, it is important to implement initiatives that can simplify its adoption and implementation in the field.

3. Challenges and Opportunities

India encounters various obstacles in its pursuit of renewable energy, such as difficulties in acquiring land, integrating renewable sources into the power grid, and the requirement for substantial financial investment. Moreover, the fluctuation of renewable energy sources requires developments in energy storage technology to guarantee the stability and dependability of the power system. Kumar, A (2023). Nevertheless, these challenges also offer prospects. India's efforts to promote renewable energy have stimulated advancements in energy storage, smart grid technology, and hybrid systems that integrate different renewable sources. Furthermore, there is an increasing focus on decentralized renewable energy systems, namely solar power, in order to improve rural electrification and expand access to energy. (Sharma, P.2021)

Comparative Analysis with the Global Context

When comparing India's renewable energy landscape with global achievements, it's evident that India ranks among the top countries in terms of installed renewable energy capacity. However, in the broader context, countries like China, the USA, and some European nations still lead in terms of total renewable energy capacity and technological innovation (IRENA, 2022).

China, for instance, has the world's largest installed capacity of solar and wind energy, reflecting its massive investment and policy support in renewable energy. The USA, with its diverse energy portfolio, also ranks high in renewable energy adoption, particularly in wind and solar power. European countries, led by Germany, Spain, and the UK, have been pioneers in integrating renewable energy into their national grids, supported by strong policy frameworks and community initiatives. (Mittal, S., 2022)

Despite these comparisons, India's renewable energy journey is remarkable for several reasons. First, India's solar energy adoption rate is among the fastest globally, thanks to its National Solar Mission and supportive state - level policies (Majid, M.2020). Second, the geographical and climatic conditions of India are quite favourable for the generation of both solar and wind energy and a major part of this potential is still unexplored. Third, it is not just the addition of renewable energy capacity but also energy access, reduction of the import of fossil fuels, and sustainable development goals in India.

Research Objectives:

To assess India's performance and issues in the process of change in energy structure, including the share of renewable energy sources. The study aims to:

1) Understand the trends in energy requirement versus availability in India during the period 2014 to 2023, highlighting the efforts to bridge the gap and achieve energy security.
2) Examine the extent to which India is harnessing its renewable energy potential, identifying gaps and opportunities for growth in solar, wind, bioenergy, small hydro, and tidal energy sectors.
3) Review the growth and development across different renewable energy sectors over time, using statistical measures to provide insights into sectoral contributions to India's renewable energy landscape.
4) Investigate the evolving composition of India's energy mix, focusing on the shift from non - renewable to renewable energy sources and its implications for sustainability and energy independence.

4. Methodology

Data Collection:

Our study employed a comprehensive data collection strategy encompassing both national and international sources. We collected data from:

- The Ministry of New and Renewable Energy (MNRE) and the Ministry of Power in India provided insights into the national stance, policy directions, and statistical achievements in the renewable energy sector.
- The International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA), offer a global context to India's energy narrative and comparative analysis with global trends in renewable energy adoption.

Data Analysis Techniques:

Our analytical approach was multifaceted, designed to dissect the complex dynamics between renewable energy adoption and its impacts on carbon emissions and energy security.

For the quantitative analysis, we specifically examined the yearly increases in solar and wind energy capacity. We determined the average growth rates by utilizing statistical metrics such as mean, median, and mode. Additionally, we performed a time series analysis to ascertain whether these patterns have exhibited an upward or downward trajectory in the last decade. In the assessment of energy security, we analysed the progression of India's reliance on imported oil and the transformation of its energy composition as the country incorporates a greater proportion of renewable energy sources such as solar and wind power. Using Python and statistical modelling, we analysed data to forecast future trends in renewable energy in India. We evaluated the impact of these changes on reducing carbon emissions and enhancing energy security. Our correlation analysis examined the influence of renewable energy development on carbon emission levels and the connection between the decrease in fossil fuel imports and the expansion of renewables in India. We employed trend analysis in time series forecasting to predict India's forthcoming energy demand and supply, enabling us to anticipate prospective energy deficits or surpluses. India's energy data was subjected to comparative analysis, which involved comparing it with international data from organizations such as IRENA and the IEA. This analysis aimed to evaluate how India's energy performance compares to global benchmarks. Ultimately, we employed time variance calculations to forecast future energy demand and supply, while also examining prospective energy deficits or surpluses through trend analysis.

These techniques together allow for a comprehensive analysis of India's energy sector transition towards renewable sources, evaluating both the environmental and security dimensions, and providing predictions for future developments.

5. Results & Discussions

India energy Requirement:

This table presents the annual energy requirement versus availability in India, highlighting the deficits or surpluses over the years, which sets the context for understanding the urgency of diversifying energy sources. ([31] Annual Reports | Ministry of New and Renewable Energy)

Table 1: India's Energy Requirement and Availability (2014 - 2023) ([31])

Year	Requirement (MU)	Availability (MU)	Deficit (MU)
2014 - 15	1068923	1030785	38138
2015 - 16	1114408	1090850	23558
2016 - 17	1142929	1135334	7595
2017 - 18	1213326	1204697	8629
2018 - 19	1274595	1267526	7070
2019 - 20	1291010	1284444	6566
2020 - 21	1275534	1270663	4871
2021 - 22	1379812	1374024	5787
2022 - 23	1511847	1504264	7583

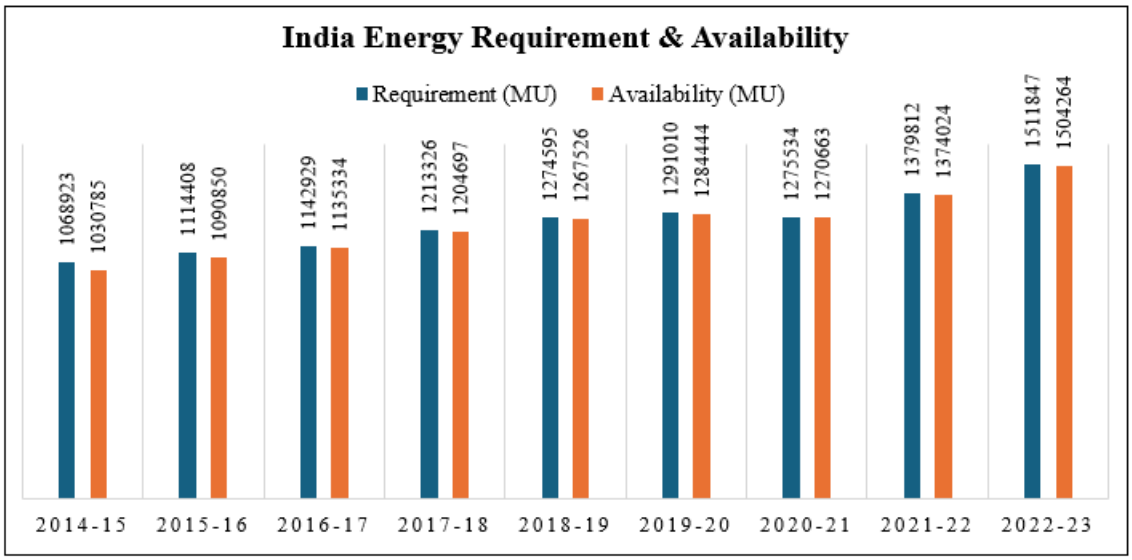

Figure 1: Graph Representing India energy requirement & availability from the years 2014 to 2023

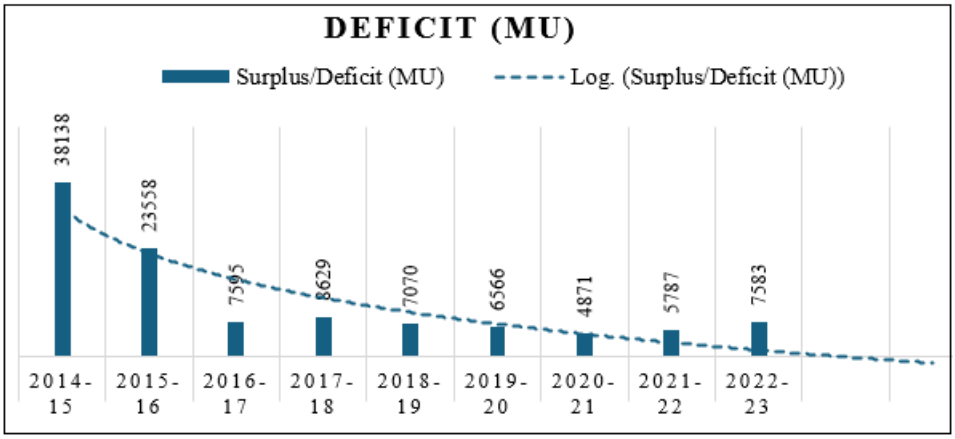

Figure 2: Time Series forecast indicating narrowing deficit between availability and requirement in the next five years indicating surplus energy production.

The data reveals a consistent upward trend in both demand (requirement) and supply (availability) of electricity, with the demand generally outpacing supply, leading to a persistent deficit. However, the magnitude of the deficit has fluctuated over the years, indicating periods of improved supply management and efficiency. Using the time series forecasting method, future projections for the next five years suggest a continuation of this growth trend in both requirement and availability. Interestingly, the forecast predicts a narrowing deficit in the immediate future, turning into a surplus by 2025, which grows through 2027. This shift towards a surplus suggests that supply improvements and efficiency gains are expected to outpace the growth in demand.

Total potential vs Installed:

Table 2: Potential vs. Installed Renewable Energy Capacity in India (as of Dec 31, 2023)

Renewable Source	Potential (GW)	Installed Capacity (GW)
Solar Energy	750	44.73
Wind Power	102	73.31
Bio - energy	25	10.2
Small Hydro	20	4.98
Tidal Energy	8	0.58
Total	905	133.8

The data presents a snapshot of India's efforts in harnessing solar energy, wind power, bio - energy, small hydro, and tidal energy, comparing their theoretical potential capacities with the capacities that have been installed and are operational (Annual Reports | Ministry of New and Renewable Energy). Solar energy shows the most significant gap between potential and installed capacity. Despite having the highest potential among all renewable sources, only a fraction of this potential has been realized. This indicates a vast opportunity for expansion in solar energy, aligning with global trends towards solar as a primary renewable energy source. Wind power demonstrates a high level of development relative to its potential, with over 70% of its estimated potential already harnessed. This suggests that India has effectively capitalized on wind energy, making it a leading source of renewable energy in the country. Further growth may be limited by geographical and technical constraints. Bio - energy, encompassing biomass and waste - to - energy, has realized just over 40% of its potential. There remains significant room for growth in this sector, which can play a crucial role in decentralized energy generation and waste management. Small hydro projects, despite their potential for contributing to the energy mix, especially in remote areas, have seen limited development. With only about 25% of their potential exploited, these projects offer substantial scope for growth, subject to environmental and economic considerations. Tidal

energy has the lowest installed capacity relative to its potential, indicating that it is at a nascent stage of development in India. Given the technical challenges and high costs associated with tidal energy, its development is slow, but it represents an untapped resource with potential for future growth.

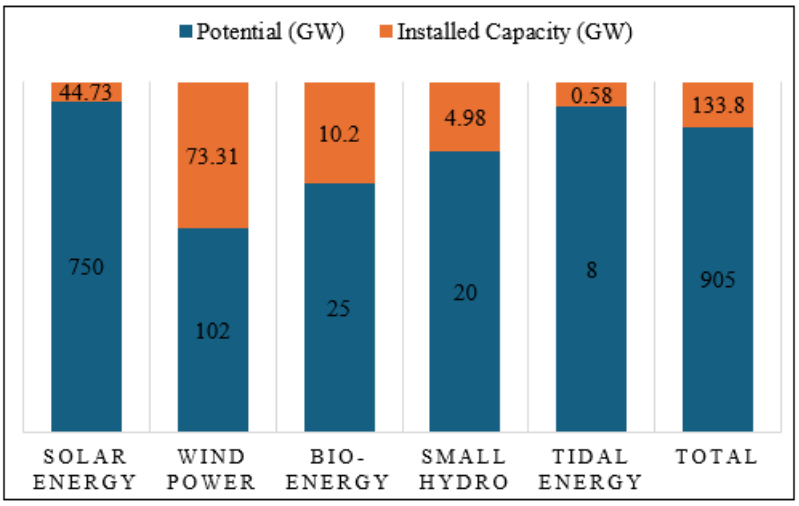

Figure 3: Picture representing the potential Vs Installed capacity of Renewable energy showing out of the total renewable energy potential only 12.5% is utilized

Cumulative Achievements in Renewable Energy Capacity – Comparative analysis:

Table 3: Cumulative Achievements in Renewable Energy Capacity (as of Dec 31, 2023)

Sector	2014 - 15	2015 - 16	2016 - 17	2017 - 18	2018 - 19	2019 - 20	2020 - 21	2021 - 22	2022 - 23	Cumulative Achievement
Wind Power	2311.77	3423.05	5502.37	1865.23	1480.97	2117.79	1503.3	1110.53	2275.55	44736.24
Solar Power	1171.62	3130.36	5658.63	9563.69	6750	6510.06	5628.8	12760.5	12783.8	73318.49
Small Hydro Power	251.68	218.11	106.38	105.95	107.34	90.01	103.65	62.09	95.4	4986.75
Biomass (Bagasse)	295.67	304.85	161.95	519.1	402.7	97	173.37	59.69	0	9433.56
Biomass (Non - bagasse)	60.05	59.24	2.2	9.5	12	0	97.24	0	42.4	828.25
Waste to Power	0	0	23.5	24.22	0	9.34	21	54.5	25	249.74
Waste to Energy (Off - grid)	9.71	5.69	11.77	5.55	6.58	19.11	20.75	34.66	52.28	333.15
Total	4100.5	7141.3	11466.81	12093.24	8759.59	8843.31	7548.11	14081.97	15274.43	133886.18

The data has been obtained from India Renewable Integration Study NREL[32] ((IRENA), 2023)). The mean, median, and mode are calculated to offer a comprehensive picture of the dataset's characteristics. They help in understanding growth patterns among different renewable energy resources.

Table 4: Sector - wise Renewable Energy Growth and Achievements (2014 - 2023)

Sector	Mean (MW/year)	Median (MW/year)	Mode (MW/year)
Wind Power	2398.95	2117.79	1110.53
Solar Power	7106.38	6510.06	1171.62
Small Hydro Power	126.73	105.95	62.09
Biomass (Bagasse) Cogeneration	223.81	173.37	0.00
Biomass (Non - bagasse) Cogeneration	31.40	12.00	0.00
Waste to Power	17.51	21.00	0.00
Waste to Energy (Off - grid)	18.46	11.77	5.55
Total	9923.25	8843.31	4100.50

This table delineates the annual and cumulative growth in renewable energy capacity across various sectors, including wind, solar, small hydro, biomass, and waste to power, from 2014 to 2023. It showcases mean, median, and mode statistics to provide insights into growth trends and sectoral contributions to India's renewable energy landscape.

6. Observations

- **Wind Power** has an average annual increase of 2, 398.95 MW, with the median growth at 2, 117.79 MW, indicating a consistent expansion without a unique mode, reflecting diverse yearly additions.
- **Solar Power** shows a significant average annual increase of 7, 106.38 MW and a median of 6, 510.06 MW, highlighting rapid growth in this sector without a unique

mode, demonstrating significant year - over - year increments.

Time series analysis of Renewable Energy growth in India:

We employed time series analysis to evaluate the growth of renewable energy in India for a systematic and insightful examination of the sector's development over time. The formulae we have used for the analysis are

- Annual Growth Rate= { (Value $_{Year\ n}$−Value $_{Year\ n-1}$) / Value $_{Year\ n-1}$ } ×100%
- Average Annual Growth Rate = ∑Annual Growth Rates / Number of Years

The table below summarizes the annual growth rates for each renewable energy sector in India from 2014 - 15 to 2022 - 23, along with the average annual growth rate for each sector:

Table 5: Annual growth rates for each renewable energy sector in India from 2014 - 15 to 2022 - 23, along with the average annual growth rate for each sector

Year/Sector	Wind Power	Solar Power	Small Hydro Power	Biomass (Bagasse)	Biomass (non - bagasse)	Waste to Power	Waste to Energy (Off - grid)	Total
2014 - 15	-	-	-	-	-	-	-	-
2015 - 16	48.07%	167.18%	- 13.34%	3.10%	- 1.35%	-	- 41.40%	74.16%
2016 - 17	60.74%	80.77%	- 51.23%	- 46.88%	- 96.29%	-	106.85%	60.57%
2017 - 18	- 66.10%	69.01%	- 0.40%	220.53%	331.82%	3.06%	- 52.85%	5.46%
2018 - 19	- 20.60%	- 29.42%	1.31%	- 22.42%	26.32%	- 100.00%	18.56%	- 27.57%
2019 - 20	43.00%	- 3.55%	- 16.14%	- 75.91%	- 100.00%	-	190.43%	0.96%
2020 - 21	- 29.02%	- 13.54%	15.15%	78.73%	-	124.84%	8.58%	- 14.65%
2021 - 22	- 26.13%	126.70%	- 40.10%	- 65.57%	- 100.00%	159.52%	67.04%	86.56%
2022 - 23	104.91%	0.18%	53.65%	- 100.00%	-	- 54.13%	50.84%	8.47%
Average Annual Growth Rate	14.36%	49.67%	- 6.39%	- 1.05%	-	-	43.51%	24.25%

Observations:

India has seen substantial growth in its renewable energy capacity over the years, with significant contributions from various sectors.

- As of December 31, 2023, the cumulative achievements in renewable energy stood at an impressive 133, 886.18 MW.
- Wind and Solar Power: Both sectors show robust growth, with solar power demonstrating a particularly high average annual growth rate of nearly 49.67%. This aligns with the strategic emphasis on solar energy in India's renewable energy portfolio. Small Hydro Power and Biomass (Bagasse) Cogeneration: These sectors exhibit negative average annual growth rates, indicating challenges or reduced focus compared to solar and wind energy. Waste to Energy (Off - grid): Shows promising growth with an average annual growth rate of 43.51%, although it's from a smaller base compared to the major sectors like wind and solar.
- The total renewable energy sector's average annual growth rate of 24.25% highlights substantial growth, driven mainly by solar and wind energy, supporting the hypothesis of India's renewable energy sector contributing to reducing carbon footprints and enhancing energy security.

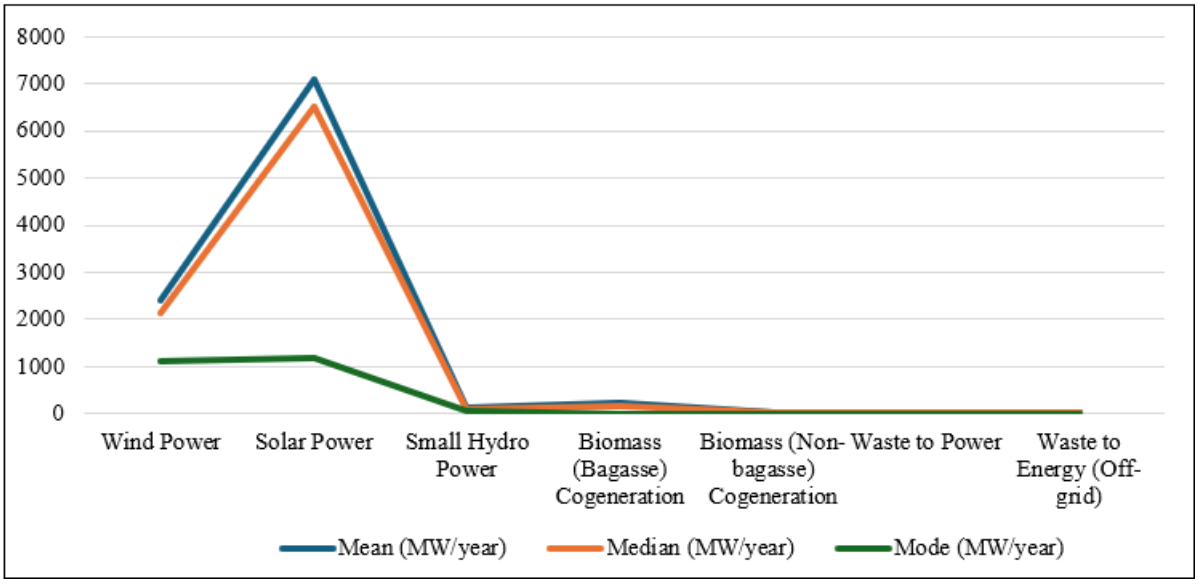

Figure 4: Representing higher Installed Energy growth rate among Wind and Solar Energy compared to other renewable energy sources

Renewable Vs Non - Renewable - India Energy Mix:

To understand the dependency of India on renewable and non - renewable resources we have analyzed data of all the energy sources for the past 10 years.

Figure 5: India's Energy Mix Percentage by Source (2013 - 2022)

Year	Oil (% equivalent primary energy)	Coal (% equivalent primary energy)	Solar (% equivalent primary energy)	Nuclear (% equivalent primary energy)	Hydro (% equivalent primary energy)	Wind (% equivalent primary energy)	Gas (% equivalent primary energy)	Other renewables (% equivalent primary energy)
2013	28.59721	55.90072	0.13044	1.214439	5.014799	1.140155	6.833914	1.000347
2014	27.52823	57.47843	0.173686	1.177634	4.917838	1.18367	6.33435	1.028754
2015	28.75324	56.68048	0.223203	1.249528	4.530507	1.112937	6.034367	1.233672
2016	30.17504	55.41721	0.37369	1.175992	4.151526	1.405147	6.135317	0.956951
2017	29.92594	55.12035	0.667152	1.111768	4.205918	1.629723	6.236744	0.925182
2018	29.59924	54.85435	1.058445	1.091703	4.071443	1.757056	6.386194	0.956943
2019	29.81127	53.58295	1.309875	1.226937	4.588224	1.792476	6.363533	1.080369
2020	28.57069	53.44759	1.74717	1.27459	4.873914	1.799091	6.842689	1.188978
2021	26.7982	55.92011	1.864733	1.150508	4.377048	1.858958	6.47747	1.224279
2022	27.57544	55.13371	2.450648	1.141604	4.504906	1.803904	5.747445	1.284795

Observations

- **Oil**: The mean percentage of oil in the energy mix is approximately 28.73%, with a median very close to the mean at 28.68%, indicating a relatively stable contribution of oil over the years. The mode, or the most frequently occurring value, is significantly lower at 26.80%, suggesting that there were years when oil's contribution dipped more noticeably compared to the average.
- **Coal**: Coal has a mean contribution of 55.35% and a median of 55.28%, illustrating a dominant and consistent presence in India's energy mix. The mode of 53.45% indicates that in at least one year, coal's contribution was notably lower than its average, yet it remains the most substantial source of energy overall.
- **Solar**: Solar energy shows a mean contribution of 1.00% and a median of 0.86%, with a very low mode of 0.13%. This disparity between the mean, median, and mode highlights the rapid growth of solar energy from a very small base, as the average and median are pulled up by more recent increases in solar energy capacity.
- **Nuclear**: Nuclear energy presents a more consistent contribution with a mean of 1.18% and a very similar median of 1.18%. The mode is slightly lower at 1.09%, indicating a slight variation in nuclear energy's share over the years but overall stability compared to other sources.
- **Hydro**: Hydroelectric power has a mean of 4.52% and a median of 4.52%, showing a balanced and steady contribution to the energy mix. The mode at 4.07% suggests minimal fluctuations in hydro's share over the decade.
- **Wind**: The mean of wind energy contribution is one.55% with a median of 1 of the study participants reported having experienced physical abuse.69% while the mode is at 1.11%. It is evident that the higher median relative to the mean suggests that the contribution of wind energy has been rising in the latter part of the decade while the mode shows that its use was relatively lower at the beginning.
- **Gas**: Natural gas has a mean of 6.34% and a median estimate of 6. This percentage is 35% with the mode at 5.75%. These numbers suggest a somewhat stable but somewhat changing picture of the importance of gas in India's energy picture, with a small trend towards the decline of the role of this resource over time.
- **Other renewables**: This category includes biomass, geothermal, and other new generation renewable sources which on average provide a mean contribution of 1.09% and a median of 1.05%, and the mode was 0.93%. This shows that while there is an increasing trend in the contribution of these sources in India's energy mix, they are still relatively small.

Time Variance Calculations:

Table 6: Year - on - Year Variance in Energy Source Contributions (2014 - 2022)

Year	Solar (%)	Wind (%)	Oil (%)	Coal (%)	Nuclear (%)	Hydro (%)	Gas (%)	Other renewables (%)
2014	33.15	3.82	- 3.74	2.82	- 3.03	- 1.93	- 7.31	2.84
2015	28.51	- 5.98	4.45	- 1.39	6.10	- 7.88	- 4.74	19.92
2016	67.42	26.26	4.94	- 2.23	- 5.89	- 8.37	1.67	- 22.43
2017	78.53	15.98	- 0.83	- 0.54	- 5.46	1.31	1.65	- 3.32
2018	58.65	7.81	- 1.09	- 0.48	- 1.80	- 3.20	2.40	3.43
2019	23.75	2.02	0.72	- 2.32	12.39	12.69	- 0.35	12.90
2020	33.38	0.37	- 4.16	- 0.25	3.88	6.23	7.53	10.05
2021	6.73	3.33	- 6.20	4.63	- 9.74	- 10.19	- 5.34	2.97
2022	31.42	- 2.96	2.90	- 1.41	- 0.77	2.92	- 11.27	4.94

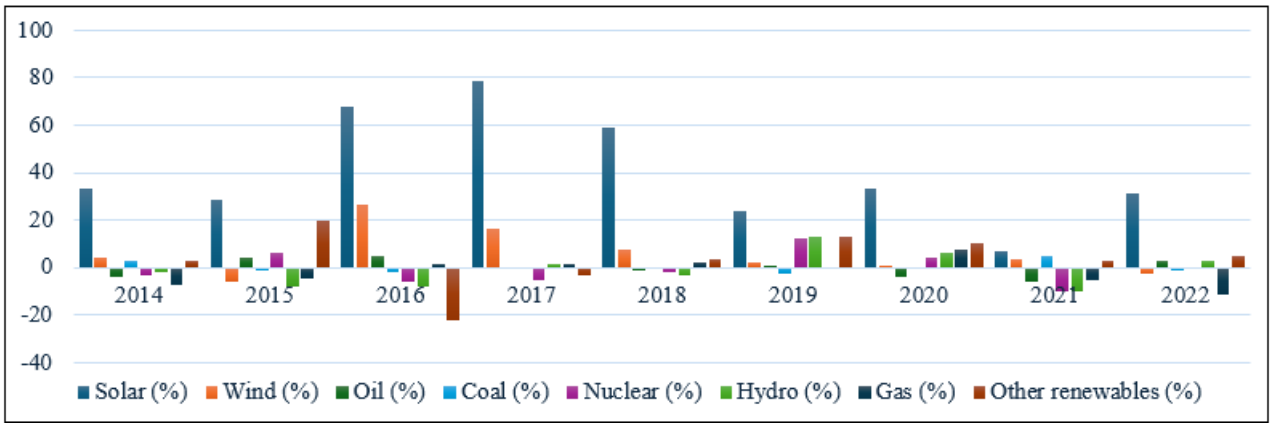

Figure 6: Graphical representation of Year on Year variance clearly representing Solar energy is constantly focussed more by the Indian Government

- **Solar and Wind Energy**: Both solar and wind energy show substantial growth rates over the period, with solar energy experiencing exceptionally high growth rates, particularly in 2016, 2017, and 2018. Wind energy also demonstrates significant growth, albeit with some fluctuation.
- **Oil and Coal**: The growth rates for oil and coal show fluctuations with periods of decline and growth, reflecting the complex dynamics of these energy sources in India's energy mix. The decline in oil in 2020 and gas in 2022 could indicate shifts towards more sustainable energy sources.
- **Nuclear, Hydro, and Other Renewables**: Nuclear energy shows a mix of growth and decline, highlighting the challenges and adjustments in this sector. Hydro power's growth rate fluctuates, with a significant increase in 2019. Other renewables show a positive trend overall, indicating a growing contribution to the energy mix.
- **Gas**: The gas sector experienced growth and decline, with a notable decrease in 2022. This fluctuation might reflect changes in domestic production or import patterns and possibly an increased focus on renewable sources.

Budget estimates:

Table 7: Budget Allocations for Power and Renewable Energy (FY14 - FY24)

Fiscal Year	Power Budget (INR Cr)	Power Revised (INR Cr)	MNRE Budget (INR Cr)	MNRE Revised (INR Cr)
FY14	10, 073	5, 411	1, 534	438
FY15	9, 544	5, 598	956	555
FY16	6, 726	8, 005	303	262
FY17	12, 253	10, 476	5, 036	4, 360
FY18	13, 881	14, 915	5, 473	4, 080
FY19	15, 047	15, 625	5, 147	5, 147
FY20	15, 875	15, 875	5, 255	3, 892
FY21	15, 875	10, 835	5, 753	3, 591
FY22	15, 322	15, 322	5, 753	7, 682
FY23	16, 075	13, 107	6, 901	7, 033
FY24	20, 671	–	10, 222	–

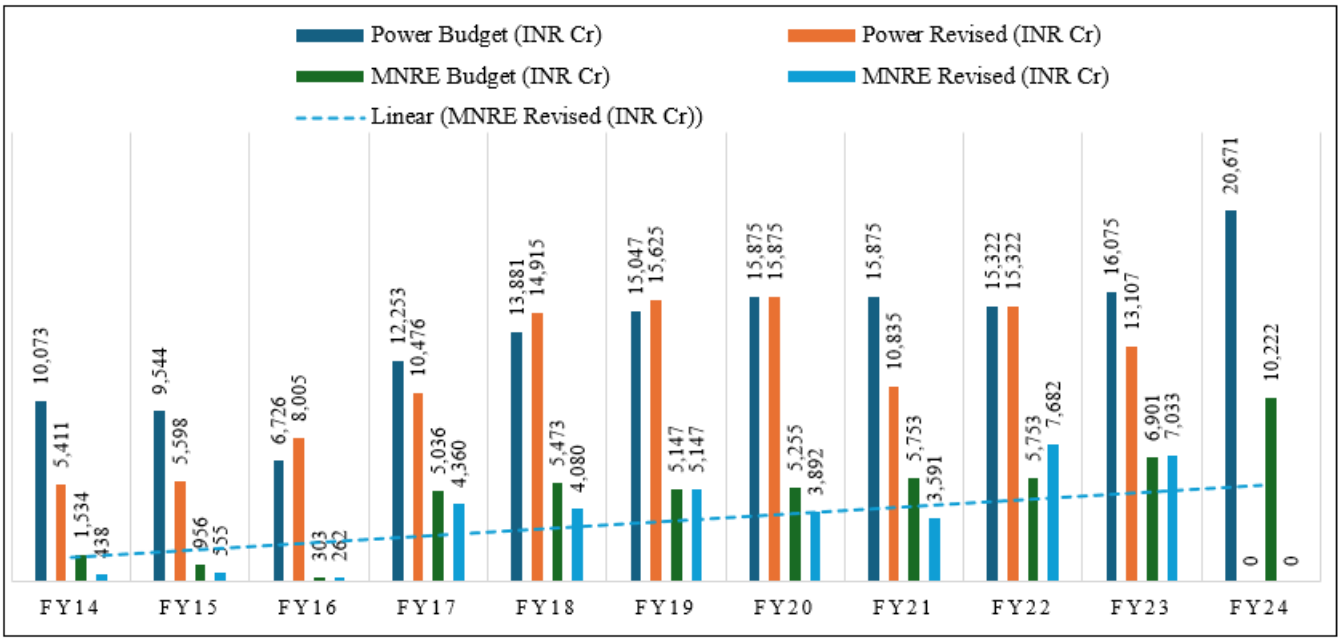

Figure 7: Representing the growing Budget spent by Indian government towards Renewable energy during 2014 to 2024

The budget allocation for the power sector has been rising from FY14 to FY24 and especially in FY24 a large amount of 20, 671 Cr has been planned for the sector which shows that there is a focus on either developing or improving power infrastructure in India. The budget allocations in MNRE are also on an overall rising trend with a significant improvement in FY24 to reach 10222 Cr. This trend demonstrates the Indian government's increasing focus on the share of renewable energy in the country's total energy consumption and the government's attempts to fulfill the obligations assumed under the Paris Climate Agreement. The numbers for FY22 and FY23 are much higher than the original budget indicating perhaps a greater emphasis on new investments in renewable energy during these years.

The trend in the MNRE budget for the FY24 indicates future plans of rapid growth or integration of renewable energy technologies which may include solar and wind energy, energy storage systems, and the power distribution network for integrating renewable energy.

7. Conclusion

The evaluation of energy needs and supply, renewable energy prospects and capacities, sector - wise performance, and budgetary provisions shed light on India's energy progress and issues.

Energy Requirement vs. Availability
The energy consumption in India has been growing steadily from 2014 to 2023, but the supply has been somewhat lower than the demand, which has led to a deficit. However, fluctuations in the deficit magnitude suggest periods of improved supply management. Future projections indicate a trend towards meeting and surpassing demand by 2025, suggesting significant strides in energy supply efficiency and management.

Renewable Energy: Potential vs. Installed Capacity
The gap between the potential and installed capacities of renewable energy sources highlights the untapped opportunities in India's energy sector, especially in solar energy, which has the highest potential yet realizes only a fraction of it. Wind energy shows a high development level, indicating effective harnessing of available resources. Other sectors like bio - energy, small hydro, and tidal energy present growth opportunities but face challenges such as technical constraints and economic viability.

Sector - wise Renewable Energy Achievements
The analysis of cumulative achievements in renewable energy capacity from 2014 to 2023 reveals significant growth, particularly in wind and solar power, which have witnessed robust expansion. The statistical analysis using mean, median, and mode further illustrates the growth patterns and sectoral contributions, with solar energy showing the most substantial average annual increase. However, some sectors like small hydropower and biomass cogeneration exhibit negative growth rates, indicating areas that require focused development efforts.

Time Series Analysis of Renewable Energy Growth
The time series analysis underscores the considerable growth in India's renewable energy capacity, with solar power showcasing an exceptionally high average annual growth rate. This sector's strategic emphasis aligns with India's renewable energy portfolio's broader objectives. The evaluation also shows the dynamic development and the problems of different types of renewable energy sources, which gives an understanding of the sectoral changes and the general trend towards the transition to a green energy system.

Renewable vs. Non - Renewable: India's Energy Mix
The analysis of the energy consumption in India during the last decade reveals the stable share of oil and coal while the renewable sources of energy such as solar and wind energy demonstrated rather high growth rates. This transition shows

the intention of India to diversify and reduce the share of the energy produced from non - renewable sources in line with global sustainability trends.

Budget Estimates for Power and Renewable Energy

The rising budget allocations for the power sector and the Ministry of New and Renewable Energy (MNRE) from FY14 to FY24 show India's intention to improve its energy infrastructure and focus on renewable energy. The proposed budget for FY24 shows a steep increase in the MNRE budget, which indicates the government's intent to aggressively promote renewable energy technologies, thereby underlining the government's method to meet future energy requirements.

Disclosure Statement

As per the policy of Taylor & Francis and my ethical responsibility as a researcher, I am declaring that I do not have any direct or indirect financial or business interest in any company involved in the research mentioned in the enclosed paper I am not a consultant to any such company, and the research was not funded by any such company. I have reported this no conflict fully to Taylor & Francis.

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