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RESEARCH ARTICLE

Policies for Balancing Climate Change Objectives and Energy Transition Goals of India: Heading towards Sustainable Energies

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ABSTRACT

India, yet another of the fastest-growing economies worldwide, exhibits a low yearly per capita carbon emission rate. The nation seeks to attain 'Viksit Bharat' by 2047, or 'Developed India', & reach Net Zero carbon emissions by 2070. Vision is directed by an emphasis on sustainable economic development and availability of reliable energy at affordable prices. Reconciling developmental requirements with a low-carbon trajectory is arduous, particularly when predominantly funded by domestic resources. Efficient energy sources necessitate effective battery storage technology and access to essential minerals. This paper analyzes the deal and synergies in India's quest for a sustainable energy future, evaluating diverse energy transition pathways such as renewable energy adoption, energy efficiency initiatives, and nuclear power development. The paper tries to assess the possible effects on greenhouse gas emissions, energy affordability, and economic growth, while considering and examining the challenges and opportunities related to the climate action into India's energy planning and policy framework.

INTRODUCTION

India stands at a critical juncture as it seeks to balance its energy needs with the urgent demand for climate action. India, a leading economies globally & third-largest producer of greenhouse emissions, confronts the combined issue of securing energy for its population while moving to sustainable energy sources. The country's commitment to combating climate change, reflected in its pledges under the Paris Agreement, requires a significant overhaul of its energy infrastructure, shifting from fossil fuels to renewable energy. However, this transition is not without its limitations. Balancing economic growth, job creation, and energy access with the imperative to reduce carbon emissions presents a complex dilemma. Renewable energy sources, that includes wind & solar power, offer enduring environmental advantages; yet, they necessitate significant initial expenditures and encounter infrastructural obstacles in a nation as heterogeneous as India. Additionally, the social and economic impacts of phasing out coal, which still provides a substantial portion of India’s energy, pose significant concerns.

On the global level, UK has delayed its decision to ban petrol and diesel vehicles from 2030 to 2035, while Germany had to modify its regulations on fossil fuel-powered boilers (Santos & Smith, 2023). Alternative political parties emerged in industrialized countries due to opposition to climate-related regulations that burden impoverished and low-income individuals. German enterprises are relocating due to rising energy costs, highlighting the dilemma governments face in addressing climate change (bloomberg.com).

Alternative energy sources require financial incentives to remain economically viable, but governments worldwide are financially constrained due to the pandemic and significant fossil fuel taxes (Tian et al., 2022). Geopolitical emphasis on renewable energy and electric vehicles has led to competition for essential minerals and rare earth elements, with China being a key supplier (Nygaard, 2023). Ensuring supplies during critical periods is a significant challenge. Nuclear energy is considered the most environmentally benign and secure alternative, but some nations are hesitant due to public reluctance, as seen in the cases of Three Mile Island, Chernobyl, and Fukushima (Self, 2021).

Conventional metals including copper as well as nickel are predicted to become increasingly scarce; in the coming decades, the world may require more copper than it has ever needed in human history (Radetzki, 2009). Other metals will also face shortages, leading to prohibitive energy transformation costs for most nations. The extraction of materials and minerals requires significant energy, with wind and solar capacities requiring approximately 10 EJ of energy from 2024 to 2030, representing 20% of global energy demand growth ('The Energy Transition', 2024). The manufacture & charging of electric vehicles necessitates around 10 EJ of energy for their incorporation into the worldwide fleet.

According to Vaclav Smil (2014), the switch from fossil-fuels to renewable energy sources would take decades of perseverance. The world is either incapable of or unwilling to follow this advice, as emerging nations are reluctant to reduce energy use. It is ethically indefensible to instruct these nations to sacrifice their ambitions for improved living standards, as it would allow rich countries to sustain their lifestyles in more pristine landscapes and temperate temperatures. It will require time as well as complexity to complete the switch from fossil fuels to renewable energy sources.

Paris Agreement, implemented in December 2015, succeeded in achieving the Sustainable Development Goals by limiting global temperature to a specific range (Höhne et al., 2017). Professor Mike Hulme argued that goal of limiting worldwide temperature within a particular range has overshadowed various welfare aspirations, partly due to the effectiveness of climate scientists and government negotiators in framing climate policies (Hulme, 2023). However, this metric is insufficient for encompassing the complex interplay between climate, human well-being, and ecological integrity, as it is a singular and ostensibly straightforward goal. The Paris Agreement aims to reduce global emissions, but development objectives are being prioritized over reducing emissions. Developing nations are facing a border carbon tax, contradicting the principle of shared responsibilities. Developed nations are also increasing energy consumption due to their fixation on AI, which has led to a 30% increase in emissions by 2023 (Mannuru et al., 2023). A major technology firm pledged to achieve Net Zero by 2030, but the competition to dominate AI has resulted in a significant increase in electricity demand. According to Goldman Sachs, this problem might get worse due to transmission, which is a bottleneck for the switch to sustainable energy, and the growth of data centers, with AI (Goldman Sachs, 2024).

The developed world is knowingly or unknowingly exacerbating poverty and inequality in developing nations by prioritizing emissions over economic growth. Highly developed nations, that have spent ages relying on growth plans fueled by fossil fuels, support large cuts in emissions from emerging nations (Rifkin, 2019). They implore them to enact legislative measures and production methods that depart from conventional approaches to reducing carbon emissions. The experimental nature of these approaches is evident in discussions among G7 nations on the cessation of unabated coal power plants, which are projected to close by the first half of 2030 (G7, 2024). Japan and

Germany disagree, with Germany aiming to close coal plants by 2038 and Japan not setting a timeline. This creates internal and foreign strife (Landini, 2024).

Climate change impacts emerging nations disproportionately, as they are sensitive and less adaptable. Developing nations are crucial in addressing the issue, acknowledging the need for significant reductions in greenhouse gas emissions. They have set Nationally Determined Contributions (NDCs) based on resource provision from rich countries. Access to technology as well as financial resources, that are expected to total between USD 5.8 and $11.5 trillion by 2030, are required for low-carbon development pathways (Standing Committee on Finance, n.d.). Developing countries struggle to achieve economic growth and lasting prosperity, which are essential for halting climate change, due to a lack of funding and technological advancements.

We must evaluate the advantages of mitigating climate change against costs of transitioning to alternative energy as well as agricultural systems to ascertain the optimal path of action (Brown, 2024). As stated by Mike Hulme "Climate change is not the only issue, as future scenarios where a global temperature increase over 2°C may yield better outcomes for political stability, human well-being, & ecological integrity compared to maintaining global temperature at 1.5°C" (Hulme, 2023). India's growth strategy focuses on addressing climate change repercussions while prioritizing developmental priorities.

RESEARCH METHODOLOGY

This paper uses qualitative method approach and focuses on evaluating and detailed analysis of policies on the national level and their impact on energy transition goals in India. This research thoroughly goes through the secondary data available on websites, government manuals, newspapers and literature available regarding the different policies that are brought into play to suffice for the knowledge required in the paper. Databases like Scopus and Google scholar were used by using keywords like 'energy transition India', Role of economic policies on climate change', 'environmental governance' 'climate change in India', 'Policies effecting climate change', 'Government schemes and incentives' etc. and were separated by adding 'AND' or 'OR'. Data from past 10 years were considered for efficient analysis. This paper considered existing policy documents, legislative frameworks, and official reports to understand the current status of the country. The data was extensively researched and then collated for interpretation.

RESULTS

After thoroughly collecting the data and reading through the paper and manuals available we have tried to interpret the present status of India, followed by climate adaptation strategies and challenges faced by the developing nations like India.

Overview of Climate Adaptation by India

The process of adapting to climate change include taking steps to lessen vulnerability to its consequences, which include extreme weather, rising sea levels, a decline in biodiversity, and shortages of food & water (Wise et al., 2014) (Moser & Ekstrom, 2010; Jam et al., 2011). Low-income nations more vulnerable to economic repercussions, with a meta-analysis showing that income loss from a 2.5°C increase is higher for lower-income nations (Tol, 2024; Assaf et al., 2024). Rich nations are able to adapt to warmer climates because they have access to infrastructure, healthcare, and adaptive technology that offer protection. Lower-income nations face significant opportunity costs and resource scarcity, making them more vulnerable and susceptible to economic instability (Collier, 2008). Economic growth improves a nation's capacity for adaptation and fosters resilience, making sustained economic expansion the most effective safeguard against climate change for developing nations.

India, a nation susceptible to climate change, has brought in multiple strategies to address this issue (germanwatch.org). The NAPCC focuses on adaptability, with seven out of nine missions dedicated to this area. PMKSY & NICRA aim to develop Indian agriculture more climate-resilient. The Saubhagya Scheme, Swachh Bharat Mission, Pradhan Mantri Awas, & Yojana Mahatma Gandhi National Rural Employment Guarantee Act, boost economic resilience as part of India's adaptation efforts (Chaturvedi, 2021). India's Initial Adaptation Communication shows that adaptation-related expenditure accounted for 5.60% of GDP in 2021-2022, up from 3.7% in 2015-2016. This highlights the government's focus on climate resilience and adaptation, while also highlighting the strain on domestic resources. Improving adaptation financing could facilitate India's attainment of its long-term sustainable development and economic growth objectives (Sathaye et al.,2006).

India's coastal areas are more susceptible to climate change, therefore protecting wetlands and mangroves is vital. Wetlands are known to provide a buffer against storm surges and flooding, absorb excess precipitation, and serve as natural coastal barriers (Burkett & Davidson, 2012). They also support local populations through fishing, agriculture, cattle, and fuel production, addressing food security challenges. Since 2014, 56 additional wetlands have been designated as Ramsar areas, covering more than 1.33 million hectares (Tshering & Dorji, 2024). The Indian government introduced the 'Amrit Dharohar' program in the 2023 Budget to promote nature tourism in preserved Ramsar sites. The Mission Sahbhagita is a significant advancement in participatory conservation and wetlands use, involving communities in the development of wetland health cards, validation using ground-truthing methods and satellite data, and advocating for 'Wetland Mitras'. These initiatives involve women, youth, local communities, and the commercial sector.

Present Status of India on Climate Change

In India, National Action Plan on Climate Change (NAPCC) is mission-driven (NAPCC, 2021). The initiative seeks to boost India's economic growth and environmental sustainability. It has nine national missions on solar energy, Himalayan ecosystem preservation, sustainable agriculture, water resources, climate change strategy, human health, sustainable habitats, energy efficiency, and forestry. The program includes climate actions like adaptation, mitigation, and demand-side management. States & Union Territories are advised to create their State Action Plans on Climate Change (SAPCC) in alignment with the NAPCC recommendations. 34 SAPCCs are in operation at present, concentrating on cross-sectoral & sector-specific priority initiatives (Mishra & Mazumdar, 2014). India has increased installed solar power capacity by 15.03GW between 2023 and 2024, demonstrating substantial progress in combating the effects of climate change (Ministry of New and Renewable Energy, n.d.). Announced in June 2023, 8^{th} cycle of Perform Achieve & Trade (PAT) (Bureau of Energy Efficiency, n.d.) initiative aims to save 0.3370 MTOE in industries such as textiles, aluminum, cement, chlor-alkali, steel& iron, pulp & paper. Both energy savings and greenhouse gas emissions have declined as a result of this approach.

India has accomplished most of its Intended Nationally Determined Contributions (INDC), including the aim of sourcing 40% of its installed electrical power capacity from non-fossil fuel energy by 2021 and achieving a 33% reduction in GDP emission intensity from 2005 levels by 2019. The 2030 Nationally Determined Contribution was revised in August 2022 (unfccc.int) to incorporate a 45% decrease in emissions intensity and a 50% share of non-fossil fuel energy capacity by 2030. By May 2024, 45.4% of installed energy generation capacity was non-fossil (powermin.gov.in). India anticipates producing 2.5 – 3.0 billion tons of carbon sink via tree as well as forest cover by 2030, following the generation of 1.97 billion tons from 2005 – 2019 (Prasad, 2022).

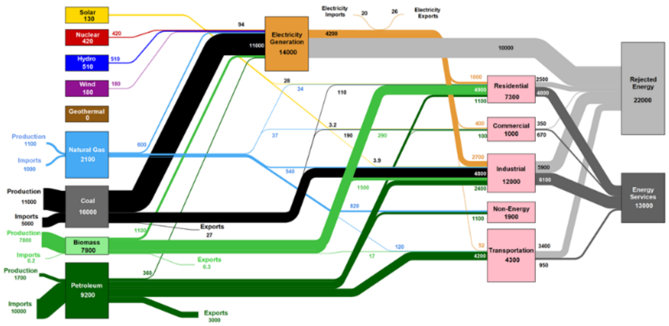

Figure 1: **Energy Flow in India (a total of 37,000 petajoule (PJ) 34 in 2017) (Source: Lawrence Livermore National Laboratory. https://flowcharts.llnl.gov/commodities/energy)**

In December 2023, India sent its Third National Communication to the UNFCCC, outlining its greenhouse gas emissions, vulnerability to climate change, and steps taken to reduce emissions and prepare for its effects (unfccc.int). At 75.81 percent, energy was the biggest contributor to anthropogenic emissions. Agriculture ranked second (13.44%). Waste ranked third at 2.34 percent and industrial process & product use 8.41%. Landscape, land-use change, and forestry sequestered 485,472 GgCO2e emissions in 2019, sustaining a net sink (Zhang, 2017). In 2019, the net national emissions of India increased to 26,46,556 GgCO2e.

India has seen a 4.56 percent increase in total national emissions since 2016, thanks to various economic initiatives and energy conservation schemes (Mohan et al., 2019). This growth rate is lower than the country's GDP growth, which saw a CAGR of nearly seven percent from 2005 to 2019. This suggests that India has successfully separated its GDP's emission intensity from its economic development in relation to greenhouse gas emissions. India is the sole G20 nation aligned with a 2-degree Celsius warming target (www.ifc.org), and these results have been achieved largely with local resources. In order to achieve the targets, set forth in the UNFCCC & the Paris Agreement, industrialized nations require access to affordable finance and technology in order to meet the estimated USD 2.5 trillion in financing required to reach the National Development Goals (NDC) by 2030.

India's Present Energy Structure and Efficiency

India's energy demands are anticipated to rise by 2 to 2.5 times by 2047 to meet its economic growth targets (niti.gov.in). To combat climate change and ensure social and economic development, the country must accelerate its energy transition. Attaining Net Zero by 2070 necessitates a deliberate transition to non-fossil fuels, enhanced energy production and consumption efficiency, and the incorporation of renewable energy into India's energy framework (Garg et al., 2024).

In 2022-23, India's major energy composition was primarily comprised of fossil fuels, with more than 84% sourced from coal, oil, and natural gas. However, renewable energy sources have transformed the electricity market, with 45.4% non-fossil power capacity in May 2024 (mospi.gov.in). The In 2022-23, India's major energy composition was primarily comprised of fossil fuels, with more than 84% sourced from coal, oil, and natural gas. However, renewable energy sources have transformed the electricity market, with 45.4% non-fossil power capacity in May 2024 (Ministry of Statistics and Programme Implementation, 2024). The PM-Surya Ghar Yojana, initiated in February 2024, seeks to augment solar capacity by 30 GW and diminish CO2 equivalent emissions by 720 million tons, while creating 1.7 million employments (PIB, 2024). The government released the national offshore wind energy strategy as well as lease laws for 2023, designating numerous offshore zones for development (Ministry of New & Renewable Energy, 2023). With financial incentives for the manufacturing & manufacture of electrolysers, India Green Hydrogen Mission aims to generate five million tons of renewable hydrogen by 2030 (PIB, 2024). Manufacturers of electrolysers & producers of green hydrogen have been given the opportunity to submit proposals under the Strategic Interventions for Green Hydrogen Transition program (PIB, 2024).

India's green hydrogen production goal faces challenges such as production and delivery costs, demand-side issues, and capital and infrastructure costs. The cost of green hydrogen production is influenced by electrolysers and renewable energy inputs, as well as capital, water supply, treatment, storage, distribution, hydrogen conversion, and infrastructure (Ishaq et al., 2022). The renewable sector faces challenges like intermittency and land requirements for solar and wind energy generation, which affect the overall cost of green hydrogen production.

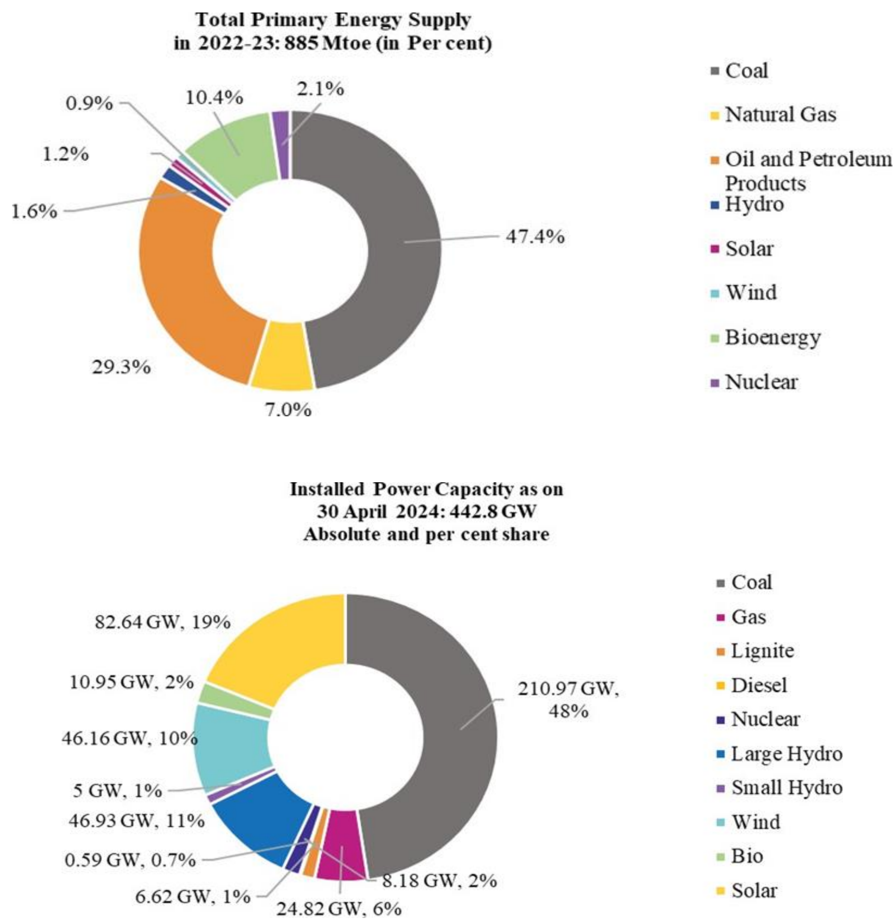

Figure 2: India's Primary Energy Supply Mix in 2022-23 and Installed Power Capacity in 2024 in terms of fuel sources (Source: Data obtained from NITI Aayog and Central Electricity Authority (https://cea.nic.in/installed-capacity- report/? lang)

India's energy consumption is primarily based on biomass, with a significant portion coming from fossil fuel imports (Garg, 2012). This is mostly because native coal is employed to produce energy. However, the increase in solar rooftop installations, solar appliances, as well as LPG-based cooking is anticipated to alter the application of biomass (Indora & Kandpal, 2018). Petroleum, 85% imported, faces challenges due to price volatility as well as restricted access to natural gas. Coal, accounting for 70% of India's electricity output, is crucial in industries like sponge iron, steel, paper, & cement. Government is promoting renewable energy integration, but a shift towards cleaner coal is needed. This initiative seeks to gasify 100million tons of coal by 2030, employing surface coal and lignite (Henderson & Mills, 2009). This technique has the potential to reduce imports and emissions. Coal bed methane extraction, coal-to-hydrogen conversion, carbon capture and storage, and coal washery beneficiation are supplementary projects (Davis & Hower, 2017). Advocacy for super-critical and ultra-super-critical technologies has led to reduced emissions and improved efficiency in coal power stations. The goal of the first Global Stocktake (GST), which focuses on clean energy transitions and energy security with national programs catered to various circumstances, is to double the average yearly speed of advances in energy efficiency globally by 2030.

Measures taken by India to Enhance Energy Efficiency

India wants to limit its overall emissions to about 4,584 million tons of CO_2 equivalent by 2030 by reducing its emissions intensity by 45%. To achieve the National Clean Development Goal, total emissions must be reduced by 3,753 $MtCO_2e$. India prioritizes energy efficiency in buildings and appliances, as over 50% of the 2030 building stock is yet to be established (beeindia.gov.in). A decrease in emission intensity within the building sector is crucial. Business & residential consumers currently account for 33% of total power usage; this percentage is expected to rise to 40% by 2031-32.

Standards for energy efficiency are established for commercial buildings by the Energy Conservation Building Code (ECBC), and for already-existing structures, a voluntary star rating system is being implemented. Net Positive & Net Zero Energy Buildings are recognized by the Shunya labeling program. The Standards and Labelling initiative educate customers about energy efficiency and cost-saving capabilities of commercial appliances (Kamaludin et al., 2021). According to the 2022–2023 Impact Assessment report, 81 billion units of power have been saved by the S&L program. The Bureau of Energy Efficiency advises consumers to swap out their outdated air conditioners for 5-star units, and the government sells high-efficiency air conditioners (Singhal et al., 2021).

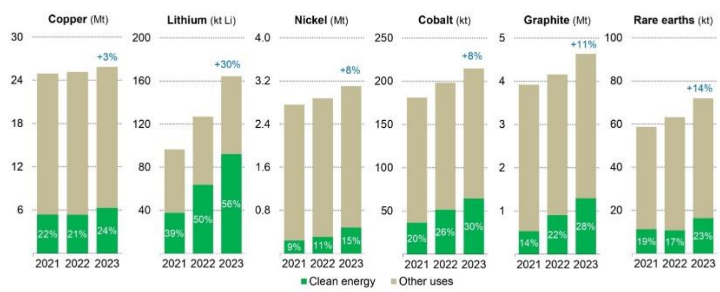

Figure 3: Demand outlook for selected minerals, 2021-2023 (Source: IEA's Global Critical Minerals Outlook 2024)

India introduced the Lifestyle for Environment (LiFE) program at COP26 in Glasgow with the goal of encouraging sustainable lifestyles to tackle climate change and environmental degradation. India has integrated energy transition strategies that align with LiFE, including promoting energy-efficient practices, sustainable mobility, and energy management. Research by the IEA indicates that global LIFE programs might enable consumers to save approximately USD 440 billion and contribute to one-fifth of the necessary emissions reductions by 2030 (Teske, 2019). A key component of India's 2030 energy efficiency strategy plan is changing people's lifestyles and behaviors. Individuals gain by living an energy-efficient lifestyle, as well as governments could redirect funding to other national objectives by delaying or reducing investments in energy infrastructure (Geller, 2012).

Mission LiFE, which BEE is putting into action in India, comprises three phases: changing government and industry policies to support sustainable production and consumption; promoting individual behavioral change; encouraging energy saving; and shaping industries and marketplaces for sustainable consumption (Malhotra et al., 2022). BEE's efficiency policies promote behavioral change and customer awareness, advocating mindful consumption through initiatives like the AC @ 24 campaign. The program focuses on consumption optimization, transitioning to efficient technology, adopting energy-saving behaviors, and upgrading existing systems.

A demand management method for the industrial sector, the PAT initiative aims to reduce emissions in energy-intensive businesses. It evaluates baseline and target energy consumption, considering net energy entering and exiting plants. The Ministry of Power has launched the Carbon Credit Trading Scheme (CCTS) as a follow-up after eight iterations were started (Okoli, 2024). The transportation industry has established fuel consumption rules for vehicles like automobiles and heavy-duty vehicles. The 'Charging Infrastructure for Electric Vehicles - Guidelines and Standards' are intended to enhance the ecology of EV charging infrastructure.

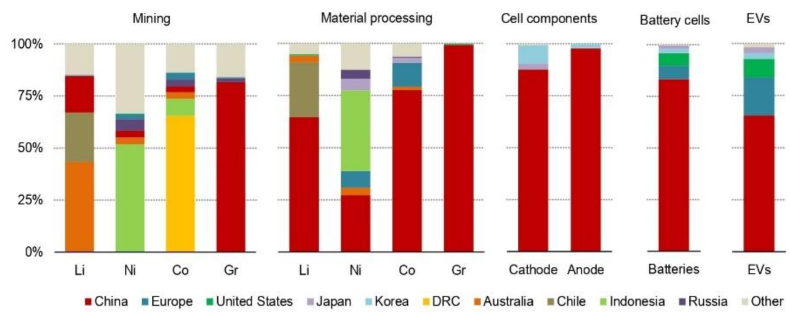

Figure 4: Geographical distribution of critical mineral global supply chains, 2023 (Source: IEA's Global Critical Minerals Outlook 2024)

Demand-side management (DSM) is a crucial strategy for reducing energy consumption, but the rise of artificial intelligence in America is causing unprecedented power demand. The pursuit of alternative energy sources, which have lower energy density than fossil fuels, leads to increased financial and resource demands, as well as geopolitical tensions. In India, DSM interventions have effectively managed peak electricity needs, postponing significant investments in infrastructure. Strategies that facilitate efficiency improvements can effectively diminish demand, such as energy-efficient pump systems in agriculture, improving local authorities' pumping systems, optimizing distribution transformer networks, and implementing star ratings for appliances and white goods (Brown, 2015).

An estimated 51 million tons of oil equivalent (MTOE) are saved annually as a result of the initiatives, which accounts for 6.6% of the country's total primary energy supply (Mehra & Kohli, 2021). As a result, there are yearly cost savings of around ₹1,94,320Crore and approximately 306 million tons less CO_2 emissions. Emissions have been lowered by 60 $MtCO_2$ under the S&L Scheme, 110.7 $MtCO_2$ under the PAT Scheme, and 125 $MtCO_2$ under energy-efficient LED bulbs.

DISCUSSION

India's dream of a low-carbon future involves balancing its ambitious climate change commitments with the energy demands of a rapidly growing economy. The energy transition must address the both challenges of decarbonizing energy production and ensuring accessibility and affordability for its diverse population. This makes a careful examination of existing policies and the formulation of innovative strategies necessary to achieve a sustainable energy mix, promote technological advancements, and foster inclusive growth.

a) Barriers to Sustainable Energy Transition in India

Without battery storage, intermittent and discontinuous supply of renewable energy compromises grid stability (Mohammed et al., 2014). As India aims for 'Viksit Bharat', increasing renewable capacity may decrease base load efficiency due to supply changes. The integration of renewable energy sources raises intermittency and dispatchability issues, making resolution crucial for the continued implementation of renewable energy.

In countries including Brazil, Australia, Italy, & India, the Levelized Cost of Electricity (LCOE) of renewable energy, especially solar energy, has dropped below that of fossil fuels (Ram et al., 2018). This is the total cost of building as well as maintaining the asset for each unit of electricity generated during its anticipated lifespan. However, the LCOE does not account for the comprehensive costs incurred by the economy, such as intermittency and dispatchability expenses. Renewable energy requires a reliable power source during periods of insufficient sunlight and wind, and energy procurement at LCOE can be seen as an implicit subsidy for producers (Beiter et al., 2021). Round-the-clock (RTC) contracts for the supply of renewable energy are one possible remedy (Andrae et al., 2022).

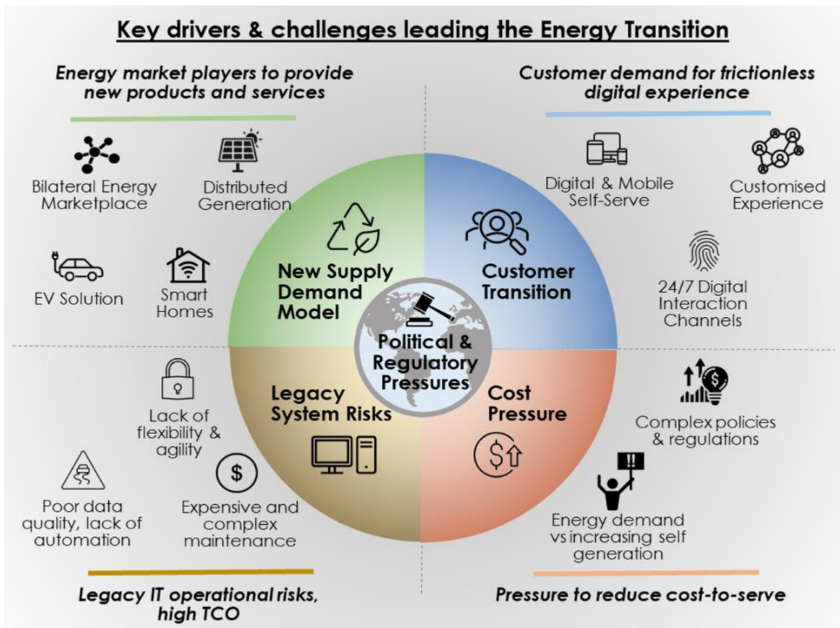

Figure 5. Key drivers and Challenges in Climate Change Transition.

Many of the technologies needed to achieve global Net Zero, like carbon capture, utilization, and storage (CCUS) and steel and cement manufacturing powered by hydrogen, are not yet commercially accessible (Hong, 2022). To achieve this, international collaboration in research and development is needed in distributed renewable energy, geothermal, electrolysers, biofuels, tidal energy, green hydrogen, offshore wind, energy storage, compressed biogas, and nuclear power (including SMR) (Blankertz et al.,2010). Grid stability & storage depend on grid balancing. To limit emissions within three decades, the innovation cycle must be reduced by 50% (Gross et al., 2018).

The demand for resources such as water and land, which are running rapidly, will continue to grow as clean fuels and renewable energy sources become more prevalent (Ellabban et al., 2014). Renewable energy sources are land-intensive and require significant land usage. The expansion of renewable technology faces significant challenges, such as land requirements. For instance, 60GW of solar power would require 600 to 900 square kilometers of land in India, the G20 country with the lowest land availability per capita (psa.gov.in) . The projected surge in land demand for renewable energy programs will increase the transition cost.

With panels lasting 25–30 years, it is anticipated that the amount of garbage generated by solar photovoltaics will reach 78 million tons worldwide by 2050 (IRENA & IEA-PVPS, 2016). There are two possibilities for managing the waste: recycling or landfilling. While landfill transportation is less expensive than recycling, soil contamination from heavy metals and hazardous substances could happen. The recycling of solar waste as scrap presents risks to the environment as well as human health, hence a thorough waste management program is required. The revised E-Waste Rules, 2022 (cpcb.nic.in) in India attempt to address disposal methods, however the problem is still quite large.

Important minerals for renewable energy and battery storage systems include lithium, cobalt, graphite, & rare earth elements (Gielen, 2021). To provide easier access to necessary minerals for a green transition, India has become a member of the Mineral Security Partnership (MSP). A list of 30 critical minerals for India has been released by the government, and national exploration efforts are being prioritized more. There had been 123 projects involving essential minerals in total by 2023, up from 59 in 2020. Through government-to-government relationships with mineral-rich countries, Khanij Bidesh India Limited (KABIL) is involved in the identification, acquisition, exploration, development, mining, as well as processing of strategic minerals abroad**.**

India faces significant obstacles in achieving a low-carbon trajectory, including technology and raw material access issues and the availability of affordable financing (Vishwanathan et al., 2018). The cost of transforming India's energy grid to meet Net Zero requirements is estimated to be trillions, with NITI's IESS 2047 model predicting a conservative annual investment of around USD 250 billion until 2047 (indiabudget.gov.in).

The CCTS proposes a compliance method where registered entities, known as obliged entities (OE), receive notifications about GHG emission intensity objectives each year during the compliance year. The objectives are amended for subsequent periods, and obligated entities must comply within nine months. They are capable of earning Carbon Credit Certificates (CCCs) determined by the discrepancy between target and actual performance in order to surpass the announced objective. The required corporation can opt to hold onto these CCCs or trade them on the carbon market. The collected CCCs may be utilized to attain compliance in ensuing years or sold. A company needs to purchase CCCs in the Indian market or utilize its banked CCCs for compliance if it doesn't fulfill its targets (Draft, 2019).

The legislation and execution of the carbon market in India for the Viksit Bharat and Net Zero objectives determines the market's efficacy (Suratwala, 2024). For the purpose of factoring emission costs into production and investment decisions, the local compliance market under the CCTS is essential. However, India should not subsidize other nations' transitions. The Mission of the Government LiFE attempts to prevent climate change and advance sustainable lifestyles that emphasize moderation & conservation. By rewarding ecologically good actions with green points, the Green Credit Programme (GCP) encourages them.

b) India's Global Efforts to Mitigate Climate Change Challenges

India has taken a leading role in international initiatives to mitigate the effects of climate change. Founded in 2015 by France and India, the International Solar Alliance (ISA) seeks to deploy USD one trillion in solar investments by 2030 by inducting private sector capital through programs for technological adoption, capacity building, and guarantees (Keshwani, 2022). A pipeline of 9.5GW of solar energy capacity has been discovered by ISA among its member countries. The ISA provides subsidies amounting to USD $50,000 to assist Least Developed Countries (LDCs) and Small Island Developing States (SIDS) in establishing solar energy demonstration projects. As of March 2024, nineteen demonstration projects were in progress. ISA also trains about 4,000 individuals globally on various parts of the solar energy sector as part of its capacity building efforts.

India and the UK are launching One World, One Sun, One Grid (OSOWOG) to interlink solar energy networks globally. The initiative aims to capture solar and other renewable energy from various locations and distribute it to regions in need. The program will be executed in three phases: connecting the Indian grid to the Middle East, South Asia, and Southeast Asia, linking the operational first phase to Africa's renewable resource pool, and aiming for global interconnection of 2,600 GW by 2050 (isolaralliance.org).

A global organization called the organization for Disaster Resilient Infrastructure (CDRI) works to increase the resilience of infrastructure systems against hazards related to climate change and natural disasters (Prashar, Shaw, & Takeuchi, 2012). It is made up of national governments, academic institutions, the commercial sector, multilateral development banks, and UN organizations. Through capacity training, well-informed policy, strategic planning, and efficient management, the organization hopes to improve infrastructure resilience and, by 2050, the environment, the lives of over three billion people, along with their means of subsistence (Tadesse, 2016). The Sustainable Development Goals (SDGs), the Paris Agreement, and the Sendai Framework goals are all monitored in part by CDRI. A digital platform for knowledge exchange & co-creation called Disaster Resilient Infrastructure (DRI) Connect awarded grants to 11 projects in 13 Small Island Developing States (SIDS) in 2023 (Kaur & Tennant 2024). The purpose of the Infrastructure Resilience Academic Exchange (IRAX) Program is to improve professional development, research, and education in DRI. In 2023, USAID will provide USD 5 million to support cooperation between US universities and Indian higher education establishments.

A strategic project of the Coalition for Disaster Resilient Infrastructure (CDRI), India's Infrastructure for Resilient Island States (IRIS) seeks to offer resilience and climate adaptation solutions to SIDS. IRIS was established in 2021, and since then, Australia, India, the EU, and the UK have contributed USD 35 million toward its target of USD 50 million by 2030 (sdgs.un.org).

The Leadership Group for Business Transition (LeadIT) has been formed by Sweden and India to encourage government and corporate cooperation in order to accomplish the Net Zero goal (Mete et al. 2021). The group's mission is to bring together companies and countries that are dedicated to fulfilling the goals of the Paris Agreement. In order to promote international cooperation and create policy frameworks for an inclusive industrial transition, the second phase of Lead IT 2.0 for 2024–2026 will concentrate on low-carbon technology transfer, inclusive and equitable development, and financial support for emerging economies.

CONCLUSION

India wants to meet its energy needs and reduce carbon emissions without sacrificing its economic goals. Access to clean, sustainable energy sources—such as non-fossil fuels—is given top priority by the government since they are crucial to India's Nationally Determined Contributions (INDC) and Net Zero commitment. However, there are obstacles to the integration of non-fossil energy sources, including waste management, intermittency, and the effect of producing biofuels on food security. India has to explore a wide range of energy sources, such as nuclear power, biofuels, and renewables, in order to meet these targets. Thermal power, especially coal-fired power stations, is an important source of base-load capacity for the deep integration of renewable energy sources.

Risks present both possibilities and barriers to India's ability to innovate, adapt, and grow. To reduce emissions and improve environmental sustainability, the government's cleaner coal initiatives—such as the Coal Gasification Mission, Coal Bed Methane gas extraction, and coal beneficiation through washeries—must be supported. The introduction of ultra super-critical technology in coal power plants can reduce emissions and enhance efficiency.

India's renewable energy expansion has been successful, with solar electricity installed capacity increasing over 25-fold from 2014 to 2023. But India must avoid becoming overly reliant on imported minerals and solar PV panels, which present systemic concerns because of intricate supply chains and geopolitical considerations. In order to reduce risks and move toward low-emission paths, India needs to concentrate on a range of energy sources, such as biofuels, nuclear energy, green hydrogen, and renewable energy sources.

International collaboration in research and development is crucial for achieving global Net Zero, including hydrogen-fueled steel and cement production and steel and aluminum manufacturing with carbon capture, utilization, and storage (CCUS). Available, affordable, and accessible financial resources will drive the green transition. The discussions around the New Collective Quantified Goal must yield results necessary to achieve the temperature objective of the Paris Agreement. The world requires a more equitable strategy toward climate change, prioritizing immediate policy objectives aimed at enhancing human wellbeing rather than being overly fixated on a singular, long-term goal of global climate control.

AUTHORS CONTRIBUTION

RG was responsible for Conceptualization, analysis, writing - original draft preparation, writing - review and editing and AM for Literature review, analysis, writing - review and editing.

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