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Energy Transition – The Technological Roadmap to Net Zero Emission Target Achievement

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Recently, the World Economic Forum (WEF) has ranked India at 67th place globally on its Energy Transition Index (ETI) out of 120 countries' economies on the current performance of their energy systems across economic development and growth, environmental sustainability and energy security and access indicators and their readiness for transition to secure, sustainable, affordable and inclusive energy systems. The Index highlights India as the sole major economy with energy transition momentum accelerating across all dimensions by advancing sustainability, energy security and equity in a balanced way.

The global energy transition policy roadmap for achieving a net-zero emission target will depend on the policies and technologies adopted by countries and regions. Additionally, the world is working towards the Paris Agreement goals to limit global warming to well below 2°C above pre-industrial levels, with an aspiration to limit it to 1.5°C. India has already made strides in green energy production. It aims to become a net-zero emitter of CO_2 by 2070 and generate at least half of its power from non-fossil sources by 2030.

The technical plan of the national Energy Transition policy to Net Zero emission roadmap has been assigned in targeted tenures of short-term goals that must be achieved by 2030 with low-cost affordable Energy Conservation (EC) solutions like implementing strict energy efficiency standards for buildings energy management systems, transportation, and industrial processes as undertaken by BEE, accommodating more industrial sectors of designated consumers of fossilised primary energy. Promoting the adoption of energy-efficient technologies, such as LED lighting, electric vehicles, and smart grid systems to enhance the efficiency, reliability, and flexibility of the electrical grid is in progress. Implementation of carbon pricing mechanisms and regulations to internalize the cost of emissions and incentivize the low-carbon technologies are already in operation. MNRE is in action to encourage sustainable agricultural practices with solar water pumps, and rainwater harvesting and MoEF has mandates on afforestation to sequester carbon and reduce emissions from land-use changes. There is a simultaneous effort to decarbonize transportation: promoting the transition to Electric Vehicles (EVs) by offering subsidies and incentives and when charged with clean energy, their environmental benefits are even greater. Investment in public transportation systems and infrastructure for EV charging stations are in process. There is increased fund allocation to support R&D in advanced energy technologies, including next-generation batteries, carbon capture and storage, and advanced nuclear power plants.

India is a crucial player in the global clean energy transition, being the third-largest energy consumer in the world as of 2022. India is ensuring action to address its high carbon emissions and environmental challenges by accelerating the deployment of RE power sources, including solar, wind, hydro, and geothermal. In 2022, wind and solar made up 92% of India's capacity additions to power generation. India's electricity use grew by almost 13% YoY to 126.16 billion units in January 2023, reflecting the pace of growth in energy demand. To achieve its target of 500 GW in RE power capacity by 2030, India has implemented various measures, including the waiver of transmission system wheeling charges

for inter-state solar and wind power sales, establishing renewable power purchase obligations (RPO), and creating Ultra Mega Renewable Energy Parks. The government is also encouraging domestic RE power equipment manufacturing through Production-Linked Incentives. India has also set up innovative green energy trading platforms such as the GTAM (Green Term Ahead Market) and GDAM (Green Day Ahead Market). These platforms enable RE power generators to sell power on the open market without signing long-term Power Purchase Agreements (PPA).

The medium-term goals of the national energy transition roadmap, that has been envisaged to achieve by 2040 include primarily the upgradation and modernization of the electric grid to accommodate the increased share of RE. Implementation of smart grid technologies for better Demand Side Management (DSM) and integration of distributed energy resources. Promoting the use of electric heat pumps for heating and cooling in residential and commercial buildings including phasing out of the use of fossil fuels for heating and power generation purposes are envisaged. Finally, the long-term energy transition goals beyond 2050 must incorporate deep decarbonization to continue the shift to 100% RE sources for electricity generation. Decarbonize hard-to-abate sectors like heavy industry and aviation through advanced technologies and sustainable practices. The large-scale deployment of carbon capture and removal technologies to offset remaining emissions. Developing carbon utilization and storage methods to ensure permanent CO_2 sequestration. According to McKinsey, the energy transition in India requires substantial future investments: $9.2 trillion in annual average spending on clean energy assets, which needs to scale up by $3.5 trillion more than what it is now, amounting to around $275 trillion between 2021 and 2050.

The success of the national energy transition policy will depend on international cooperation, technological innovation, and sustained commitment to addressing climate change. Emission control targets can be achieved through the implementation of key energy transition technologies, which help reduce GHG emissions to mitigate national sustainable energy security plans with affordable energy availability, involving a combination of technologies that can enhance energy generation, distribution, and storage. These include RE power sources like rooftop SPV to large solar parks; on-shore or off-shore wind turbines; Hydroelectric power from large dams and small-scale run-of-river systems or pumped hydroelectric systems; Geothermal power from the Earth's heat including tapping tidal and wave energy from vast coastal territory. The green hydrogen produced using RE can serve as an energy carrier for transportation and industrial processes. Fuel cells can convert green hydrogen into electricity with high efficiency and zero emissions. Biomass and biofuels produced from organic materials provide sustainable sources of energy, including biogas, bioethanol, and biodiesel lowering emissions and promoting faster energy transition.

On the other side, Energy Storage (ES) technologies, such as batteries, pumped hydroelectric storage, compressed air and thermal ES, can store energy from RE sources and discharge it when needed, providing backup power during grid outages or other disruptions. Lithium-ion batteries play a vital role in energy storage, for meeting the growing needs of electric mobility, and RE storage ecosystems. As the RE generation varies and is only available for a limited time of day, the CEA envisages the installation of battery storage capacity worth 51.5 GW by 2030 to provide "round-the-clock power to end-consumers". India can leverage lithium-ion batteries and battery recycling and reuse technology to enhance ES capabilities and optimize RE utilization. Along with battery recycling, India has begun repurposing used batteries into sustainable 2nd-life Battery Energy Storage Systems (BESS), saving 98% of GHG emission compared to making new batteries, which approximately equals 176,400 Tons of CO_2e per GW of batteries. India can now leverage battery recycling technology that reduces GHG emissions by 50% compared to mining and consumes 500x less water per metric ton of raw materials to not only reduce dependence on material imports but also become a global supplier of low-carbon energy transition materials.

These technologies are rapidly evolving and becoming more affordable, making them a viable solution for enhancing Energy Resilience (ER). Incorporating ER into the energy transition technological process is crucial for ensuring a reliable and secure energy supply while reducing the environmental impact of energy production and consumption. It involves a combination of technology, infrastructure, planning, and community involvement to mitigate the risks associated with energy disruptions. To withstand ER, small-scale microgrids, localized power

systems that can operate independently of the main grid, are providing backup power during outages or other disruptions, also providing off-grid energy access to rural areas with clean and RE technologies. They can integrate RE sources, ES, and other distributed energy resources, such as combined heat and power, and provide resilience and flexibility to the energy system. IoT (Internet of Things) technologies, such as sensors, smart meters, automated control systems, and other cyber-physical systems improve the monitoring, control, and optimization of energy systems, enhancing their efficiency and reliability. They can also provide real-time data and analytics to support decision-making and improve energy management. Protecting energy infrastructure from cyberattacks is critical for ER. Robust cybersecurity measures should be implemented to prevent and respond to threats. IoT is further supported by Artificial Intelligence (AI) technologies, such as machine learning, predictive analytics, and optimization algorithms, which can help optimize energy systems capacity utilisation with EC and predict and prevent failures, reducing downtime and enhancing resilience. The successful implementation of these technologies, combined with supportive policies and investment in R&D, will play a vital role in achieving the nation's sustainable energy security and affordable energy availability while reducing the environmental impacts of energy production and consumption.

India's energy transition faces both challenges and opportunities. Accelerating the energy transition can bring numerous opportunities for India. It can create millions of jobs, enhance energy security, and tangibly reduce nationwide GHG emissions. The RE sector already employs 11.5 million people globally, with an estimated 24 million new jobs by 2030. India can serve as an example for the world by fostering what is potentially the largest green workforce in the world with the due capacity-building resources of NPTI, NISE, and National Green Job Skill Council and contributing significantly to the fight against climate change on both national and international scales.