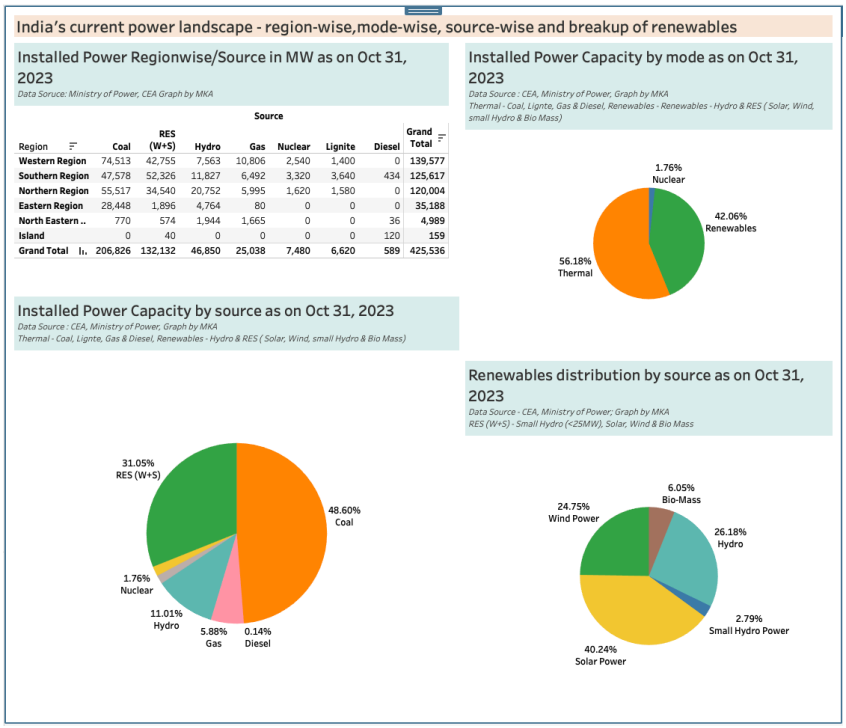
Indian Power Sector Landscape: Present and Future - Navigating the NZE Challenge

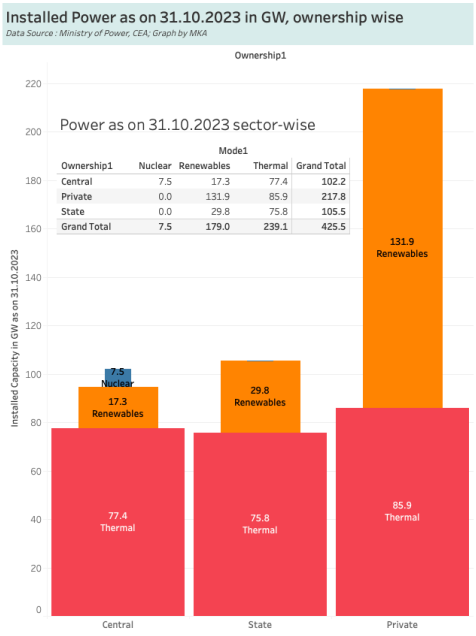
India balances blazing economic growth with a green tightrope walk, striving for quality, affordable power amidst net-zero ambitions

India's economic juggernaut hums on an intricate tapestry of energy demands. From illuminating rural villages to powering bustling metropolises, its insatiable appetite for a cost competitive electricity stands at the heart of its development narrative. However, this narrative takes a critical turn as the nation grapples with the dual imperatives of energy security and environmental sustainability. Home to one-fifth of the world's population crossing over 1.4 billon people, India's energy consumption charts an upward trajectory. Presently per capita consumption is abysmally low at 1255 kWh compared to the developed economies. Coal, the bedrock of its current grid, meets over 70% of this demand, but its reign casts a long shadow of environmental and health concerns. While coal has propelled India's growth, its environmental footprint raises pressing questions. Climate change concerns and air quality anxieties necessitate a decisive shift towards cleaner alternatives. A glance at the Per Capita CO2 emissions of G7 countries, China, Australia, and India from 1750 to 2022 reveals a stark contrast. Over the past century, G7 emissions have been notably higher. In 2022, annual Per capita CO2 emission of United States - 14.9 t and Canada - 14.2 t even China & Germany - 8 t stand in sharp contrast to India at 2 t, however, in absolute terms, India is the 3rd largest emitter of GHG emission at 2.8 Billion ton in 2022 after China & USA. Amidst these challenges, a beacon of hope emerges. India's ambitious renewable energy targets paint a vivid picture of a future powered by the sun, wind, and other clean sources. With over 20%

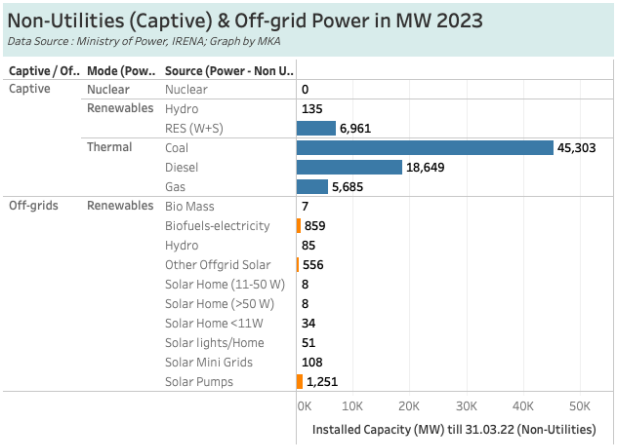


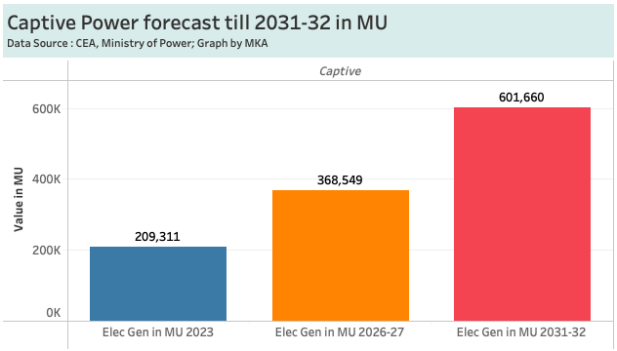
of current generation capacity stemming from all Renewables, the transition seems to be well underway but future challenges lie ahead.

India's power sector boasts a staggering installed capacity (Utilities) of over 425 GW currently, with industrially developed Western region of India with 30% share followed by Southern region with 29% share. Eastern region, coal & mineral rich though, has a share <10%. Coal-fired plants currently dominate the landscape, accounting for approximately 50% of total installed capacity with renewables over 31%. Hydropower contriBU (TWh)tes another 11%, while nuclear with <2% and Gas based at modest 6%. This diverse mix, though impressive, requires strategic management to ensure consistent and reliable power delivery. The renewable energy sector, driven by ambitious government targets and falling technology costs, is experiencing exponential growth with the share of Solar-40%, Wind- 25%, Hydro 26%, small hydro (<25MW)-3% and BioMass-remaining, in the Renewable Power basket. Solar power, especially, has witnessed a solar revolution. Wind energy too is making significant strides, particularly in coastal states & western states with strong wind resources. Please see the relevant graph. Over the recent years, private sector has been a dominating player in the India occupying over 50% share ie 217 GW followed by states with 105 GW and central govt. with 102 GW. Nuclear power capacity of 7.5 GW is exclusively with the central govt.

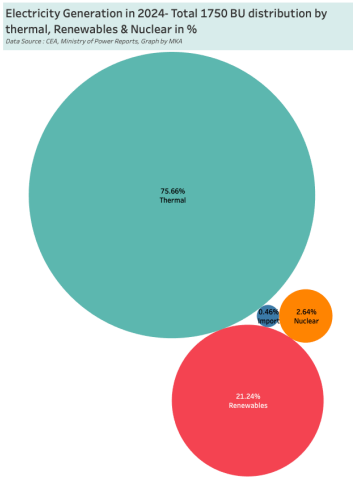


Captive power (Non-utilities), for its own consumption for an entity, independent of the main grid is an important play due to the rising cost of grid-supplied electricity, frequent power outages. The desire for reliable and high-quality power drive the interest in captive solutions, is an addition to the Utilities power capacity. For industries, cost savings and process control become additional motivators. Captive power plants can utilize diverse fuel sources, including fossil fuels like coal, diesel and gas, as well as renewable options like solar and wind. The choice depends on cost, availability, and environmental considerations. As of 2023, India's captive power capacity at 76.7 GW and constitutes by thermal power 90% and remaining with Renewable power. Captive power generation presently is 209 BU (TWh) and this is also planned to reach to 369 BU (TWh) in 2026-27 and whopping 601 BU (TWh) by 2031-32. For remote areas and communities unconnected to the grid, off-grid solutions offer light and hope. Solar mini-grids, micro-hydro installations, and standalone photovoltaic systems bring the power of electricity to underserved populations, promotes economic development, improves healthcare access, and empowers communities by fostering education and entrepreneurship. Advancements in battery storage, energy-efficient appliances, and smart grid technologies are making off-grid solutions more efficient and cost-effective. As per IRENA, off-grid installed capacity in India is ~30GW the break-up as per the relevant slide.

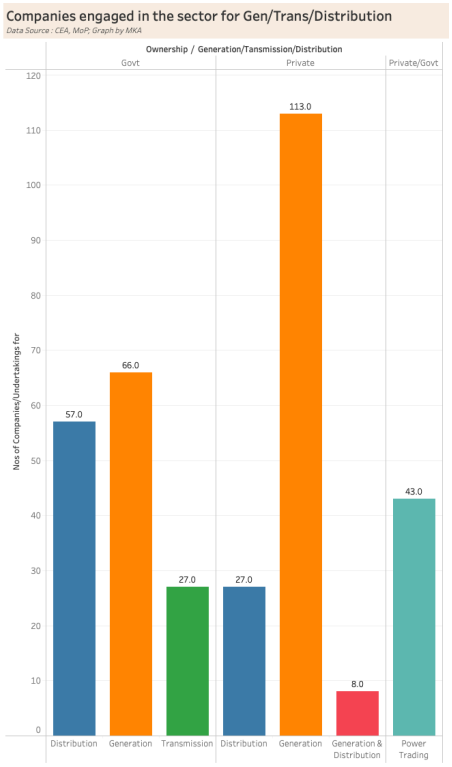




Power Generation in the current financial year ie 2024 is expected to be 1750 BU (TWh) with thermal power share at 76% is far higher than the Renewable power of 21% and Nuclear at 3%. It also includes a small power import of 8 BU (TWh) from Bhutan. The ecosystem needs a

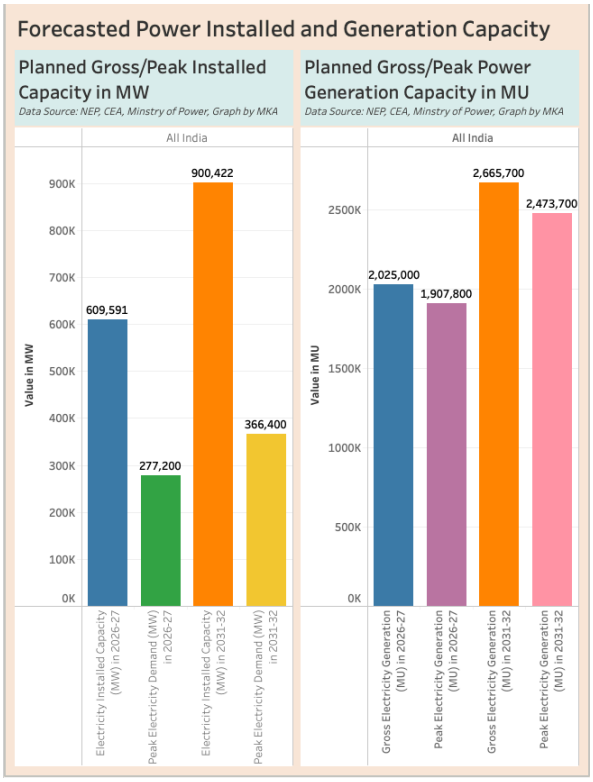


well experienced companies for generation, transmission and distribution. Presently, there are 187 companies steering the power generation with 113 companies in private sector, 66 in govt sector and 8 in mix holdings. Transmission is with 27 nos govt companies and distribution is by govt and private both with 57 and 27 companies respectively. Power trading is undertaken by 43 companies by both in private as well as in govt sectors. The transmission lines crossing over 6 million Ckt Kms with inter-regional corridors within 05 Regions spreading over the country make a nation grid in addition to the export corridors with the neighbouring countries.

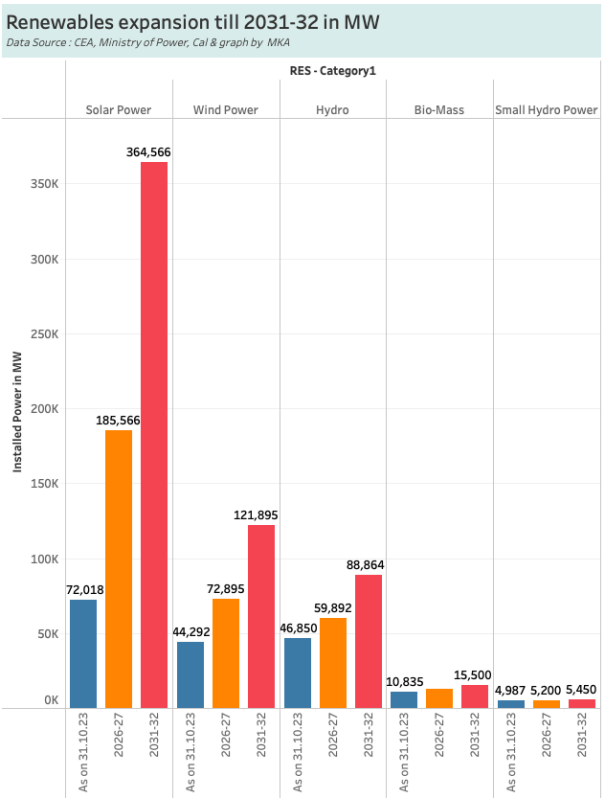


With a commitment to achieving Net-Zero Emissions (NZE) by 2070, India has charted an ambitious roadmap for its power sector. During COP 26 held at Glasgow, U.K. in 2021, one of the *Panchamrit (Hindus' sacred mixture of five foods)* was that "By 2030, India will reduce the carbon intensity of its economy to less than 45 per cent". In order to achieve the 45% target of emission- intensity reduction, preliminary analysis indicate that absolute emissions by 2030 are required to be limited around 4584 MtCO2e. Total GHG emissions in India are of the order of 2800 MTCO2 eq. The energy sector accounts for nearly 75%. Of this, electricity production contributes nearly 40%. (MOEFCC, Biennial Update Report, 2021). Unsurprisingly, India's NDC commitments seek to address these concerns through the reduction of the emissions intensity of its GDP by 33 to 35 percent by 2030 from the 2005 level and the attainment about 40 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030. This ambitious goal necessitates a drastic reduction in fossil fuel dependence and a massive scaling up of renewable energy capacity. India, an emerging economy, has a fastest growing GDP presently (>7%) and expected to be >6% in next 5 to 10 years on yoy (year on year) basis. The government's policy initiatives play a crucial role in propelling this green transition considering the various competing challenges from its economic development, large population, low cost power, NZE commitments and a sustainable power development keeping in view the regions inequality. From Production Linked Incentives (PLIs) for domestic manufacturing of batteries, solar and wind equipment favouring renewable projects, these policies create a conducive environment for clean energy investments. Emerging technologies like energy storage, particularly advanced battery systems, are game-changers for grid integration, allowing for the capture and utilisation of excess renewable energy during peak generation periods. Additionally, smart grid technologies, with their real-time data analytics and automation capabilities, optimise grid operations, gradual phasing out of coal based power and enhance efficiency.

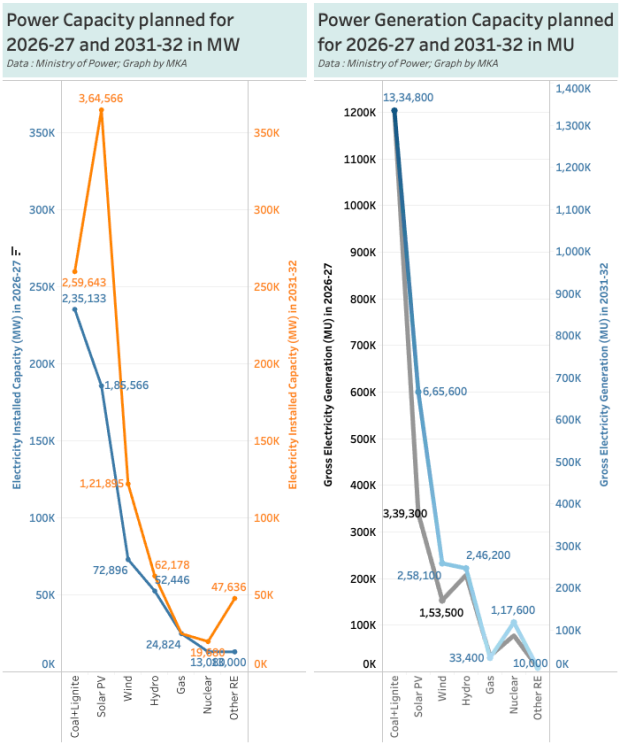
Transition to renewable energy is the corner stone of the policy and plans to add 30-50 GW of annual RE capacity to achieve the targets. At the COP28 climate change conference in Dubai, more than 130 national governments including the European Union agreed to work together to triple the world's installed renewable energy capacity to at least 11000 GW by 2030. As per IEA, Global annual renewable capacity additions increased by almost 50% to nearly 510 gigawatts (GW) in 2023, the fastest growth rate in the past two decades and global renewable capacity is forecast to reach 7300 GW by 2028. This growth trajectory would see global capacity increase to 2.5 times its current level by 2030, falling short of the tripling goal. As per CEA- Ministry of Power, India's installed power is planned to in-



crease to 609 GW with 1907 BU (TWh) power generation by 2026-27 and then to whopping 900 GW with-2473 BU (TWh) power generation by 2031-32. Renewable Power (ie Solar, Wind, Hydro, Small Hydro and Bio-

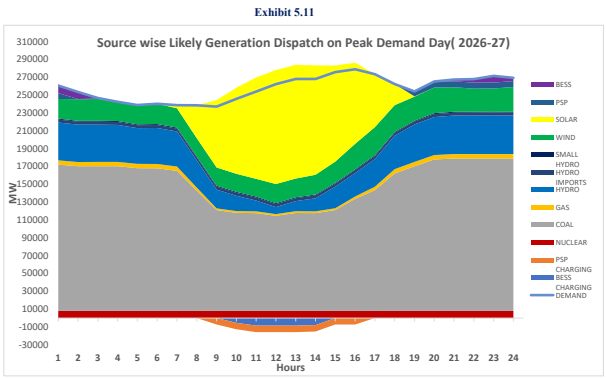


Mass) will be increased from present level of 178 GW to 336 GW by 2026-27 and 596 GW by 2031-32. Solar Power share in the renewable power shall be 185 GW by 2026-27 and 365 GW by 2031-32 from the present level of 72 GW. Wind power will be 73 GW by 2026-27 and 122 GW by 2031-32 from the present level of 44 GW. Hydro will be increased to 60 GW by 2026-27 and 89 GW by



2031-32 from the present level of 46 GW. In support to achieve NZE targets, Coal & lignite based power plant will have a marginal increase from 235 GW in 2026-27 to 259 GW in 2031-32. The gross power generation pie chat will still be dominated by Thermal 61% (59% coal + 2% Gas) in 2026-27 and decreasing to 51% (50% coal + 1% Gas) in the Gas) in 2031-32. However, Renewable power share will reach from present 21% to 35% in 2026-27 and 44% in 2031-32. In the Renewable Power, share of Solar will be 17% in 2026-27 and 25% in 2031-32 and Wind aiming to be 8% in 2026-27 and 10% in 2031-32. Nuclear share will remain at 4% level. Based on scenario analysis by CEA, in 2026-27, the BESS (Battery Energy Storage) based storage requirement will be varying from 2.1 GW/ 8.4GWh to 22.8 GW/ 91.2 GWh across various scenarios considered. In 2031-32, the BESS requirement will be varying from 38.7 GW/193.55 GWh to 67 GW/335.2 GWh across various scenarios.

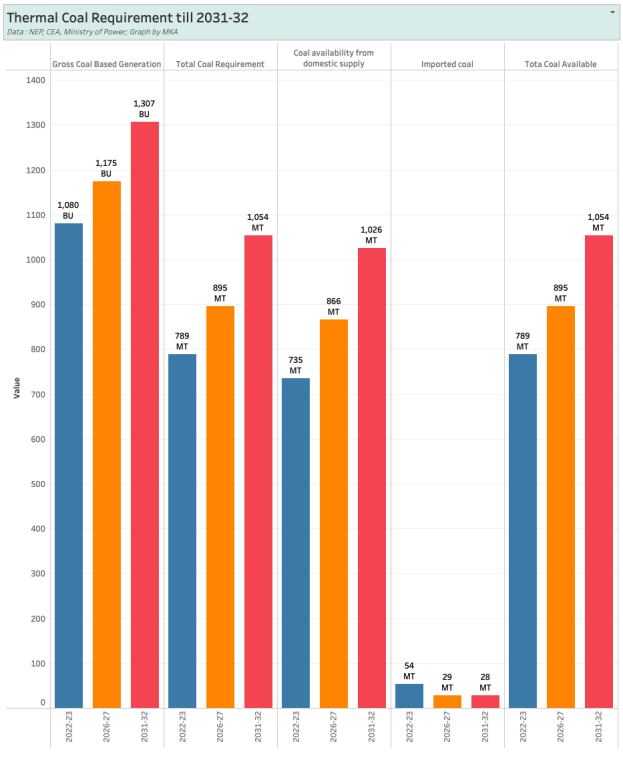
Variable renewable energy sources (VREs) like solar and wind power can be fully realized by key technologies of Energy Storage. Integrating renewables into the existing grid presents unique challenges. Their intermittent nature, dependent on weather conditions, makes grid management complex. Storage solutions, smart grid technologies, and efficient forecasting models are crucial to address variability and ensure grid stability. The grid integration challenges of the intermittent generation sources i.e. ensuring quality of supply on real time basis can be achieved by the electricity storage systems which have the capability to store excess electricity over different time horizons (minutes, days, weeks). Many grid scale energy storage systems are commercially available worldwide which includes pumped storage plants, battery energy storage systems, etc. However, many other energy storage technologies like Green Hydrogen are in nascent stages of development. Arguably there is a limit to the maximum VRE in the gris for its flexibility and reliability. Hence, VRE curtailment may be optimised as a part of cost-effective planning solution while ensuring grid reliability. As per



CEA, about 1% of RE based generation may not be absorbed during the year 2026-27 while around 3.3 % of the RE based generation may not be absorbed during 2031-32. Studies carried out are at 55% Minimum technical load but CEA regulation has been brought out as

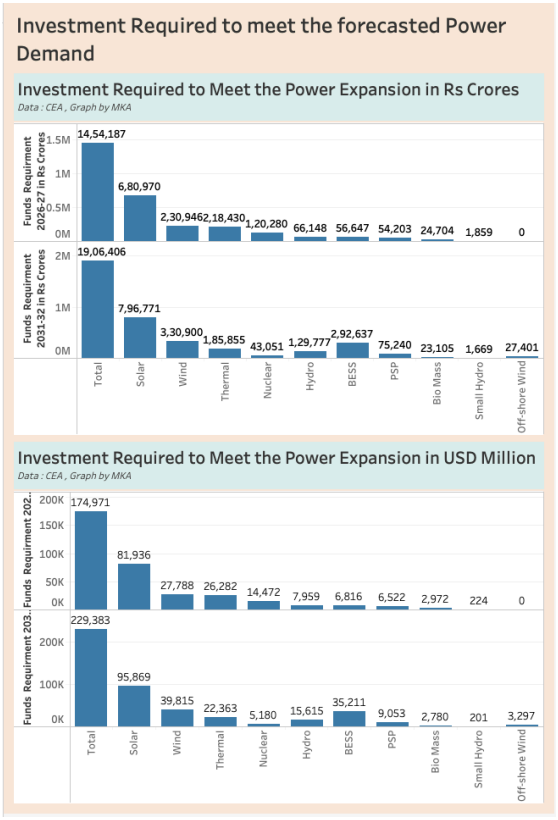
per which 40 % Minimum technical load can be achieved, considering 40% minimum technical load the RE based generation not absorbed will decrease to 0.09% and 1.29% in FY 2026-27 and 2031-32 respectively. In a paper by Lion Hirth, the welfare-optimal electricity generation mix is one of the most researched topics in numerical model-based energy economics and suggested that the very high optimal VRE shares (45% wind plus 15% solar) is a combination of high VRE cost reductions with high carbon prices and unavailability of the low- carbon technologies, nuclear power and CCS. Firm power generation like nuclear, CCUS, hydro and hydrogen will be needed for grid stability as renewable share grows.

The domestic coal requirement has been estimated to be 866.4 Million Tonnes for the year 2026-27 and 1025.8 Million Tonnes for the year 2031-32 and estimated requirement of 28.9 MT of coal imports for the plants designed to run on imported coal. The average PLF of the total installed coal capacity of 235 GW was found to be about 58.4% with 1203 BU (TWh) in 2026-27 and PLF of about 58.7% with 1334 BU (TWh) in 2031-32. The average CO_2 emission rate from coal based stations in the



country has been on declining trend indicating improvement in efficiency of power generation from coal based power plants. During 2021-22, the country has achieved Fly Ash Utilisation of 259.86 Million tonnes with percentage utilisation of 95.95%. The total CO_2 emissions projected will increase from 1002 Million Tonnes in 2021-22 to 1057 Million tonnes in the year 2026-27 and 1100 Million Tonnes in 2031-32. The average emission factor is expected to reduce to 0.548 kg CO2/kWh in 2026-27 and to 0.43 kg CO_2/kWh by the end of 2031-32.

Financing the Shift: From Subsidies to Sustainable Models: The transition to a cleaner future requires robust financial mechanisms. As per Mckinsey, Global Annual investments in energy sector projected to grow up to 5% per year, reaching $1.3-2.4 trillion by 2040. Grid investments will see highest growth. Cost of power generation expected to decline but share of grid costs will likely grow from 40% to 60-70% by 2050. While government subsidies have initially fuelled renewable energy growth, attracting private investments and de-



veloping innovative financing models, such as green bonds and carbon credits, are critical for long-term sustainability. Indian Power sector has planned the total investment in debt:equity ratio of 3:1 or 25% equity with 75% debt level. India Power sector needs the total investment of US$ 175 Billion till year 2026-27 and additional US$ 230 Billion to meet the target of year 2031-32. Major investments will be in the solar power having US$

Funds Requirements till 2031-32

Data: NEP, CEA; MoP; Graph by MKA

Source (Fund Requirments)	2026-27 in Rs Crores	2026-27 in USD Million	2031-32 in Rs Crores	2031-32 in USD Million
BESS	56,647	6,816	292,637	35,211
Bio Mass	24,704	2,972	23,105	2,780
Hydro	66,148	7,959	129,777	15,615
Nuclear	120,280	14,472	43,051	5,180
Off-shore Wind	0	0	27,401	3,297
PSP	54,203	6,522	75,240	9,053
Small Hydro	1,859	224	1,669	201
Solar	680,970	81,936	796,771	95,869
Thermal	218,430	26,282	185,855	22,363
Wind	230,946	27,788	330,900	39,815
Grand Total	1,454,187	174,971	1,906,406	229,383

82 Billion till 2026-27 and additional US$ 96 Billion till 2031-32. Following solar, wind power will have investments US$ 28 Billion till 2026-27 and then additional US$ 40 Billion till 2031-32. Investments in BESS, offshore wind and PSP (Pumped Storage Hydro) are also planned. Nuclear remains on a stable front which requires a review to increase further and may be some investment for R&D to develop Thorium based power and India has the largest Thorium reserves in the world and may have the potential in this space. The detailed breakup is in the relevant table.

Challenges and Opportunities: The Road Ahead is Paved with Both: Despite the ambitious plans meeting both growth with NZE challenges mitigation and supporting policies, hurdles remain. Land acquisition for renewable energy projects, high upfront costs of storage solutions, financing the mammoth expansion and the need for a skilled workforce in new technologies are some of the significant challenges that need to be addressed. Conversely, the transition presents immense opportunities for job creation in green industries, attracting foreign investments, and fostering technological innovation.

Conversion:
I unit of electricity = 1 kWh,
1 Gigawatt-hour (GWh) = 1 Million Units (MU)
1 Billion Units (BU) = 1000 Gigawatt-hour (GWh)
1 Billion Units (BU) = 1 Terawatt-Hour (TWh)

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