FICCI

POWERING INDIA'S ENERGY TRANSITION

Strategies to Accelerate Renewable Integration and Decarbonization

January 2025







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FICCI also conveys its appreciation to various organizations, associations, and individual experts in the sector for sharing their insights and contributing to the report. Their views have contributed immensely to finalizing the report.

In the report, an attempt has been made to comprehensively cover the trends & developments, opportunities, challenges, and recommendations pertaining to the energy transition journey of the nation in consultation with industry and other stakeholders in this sector.

At the end, FICCI acknowledges the contributions made by all those associated with the report.

Foreword

Aligned with India's commitments towards climate action, Energy Transition has become an imperative agenda for the country. Five-point action plan under Panchamrit Framework articulates the nation's climate objectives and has been the cornerstone of our commitment towards sustainability.

India is pioneering a new model of green growth development through large-scale deployment of renewable energy to support economic development. While mitigating climate change, this pathway also improves energy security & access for its citizens. The journey towards 'Net zero by 2070' is challenging but full of emerging opportunities & evolving dynamics across industrial decarbonization, grid stability and energy supplies.

This seminal document, developed in collaboration with Boston Consulting Group (BCG), highlights the initiatives required to create a robust ecosystem which will help in achieving India's energy transition & decarbonisation goals. It also covers the crucial role of new policy instruments and technological advancements needed for balancing energy demand and supply. The report outlines key recommendations for actions required to overcome some of the impediments to growth of clean energy in India.

We believe this report will be helpful in propelling the next wave of clean energy transition in India and stimulate policy direction in the context. We are thankful to BCG for partnering with FICCI for this initiative. We also thank all our stakeholders who contributed to the development of the report.

We are hopeful that you would find the recommendations in the report useful.



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01

The Irreversible Megatrend of Global Energy Transition

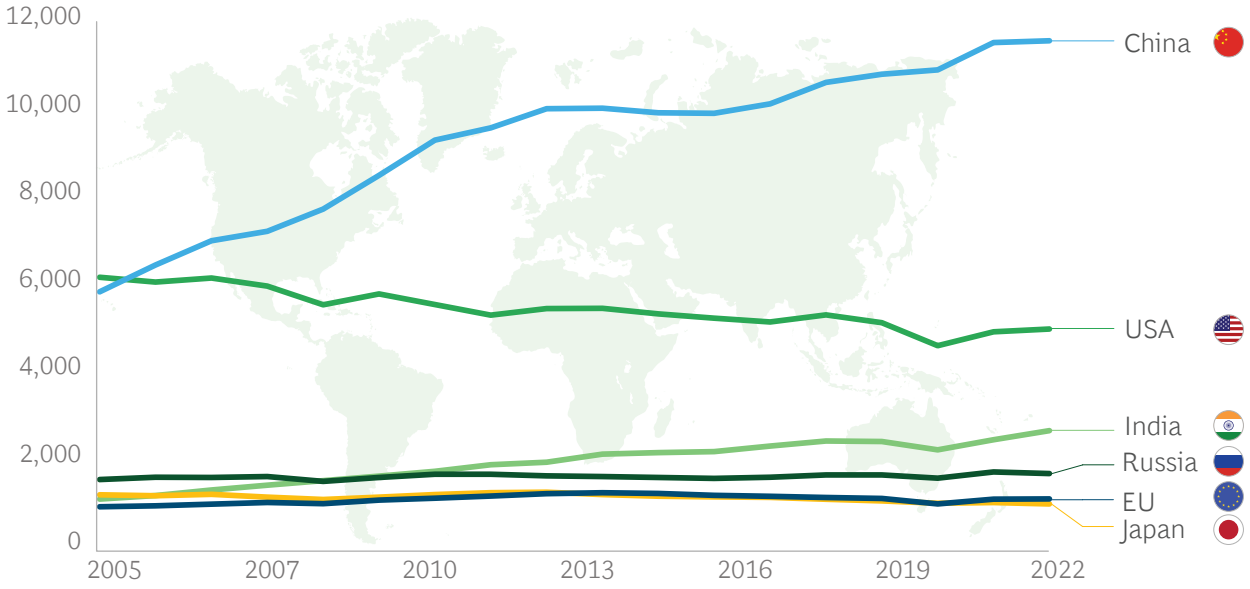
1.1

Global Energy Transition and India Leadership

Top 6 Emitters Contribute to 67% of Global CO_2 Emissions

The current global emissions landscape paints a complex picture, with major economies contributing significantly to greenhouse gas emissions and **Renewable Energy (RE) transitions**. In 2023, global energy-related CO_2 emissions grew by 410 Mn tonnes **equivalent of CO_2 to reach an unprecedented 37.4 Gt**[1]. The top six global emitters—China, the United States, the European Union, India, Russia, and Japan—collectively account for approximately 67% of global CO_2 emissions. Notably, China itself accounts for a staggering 34% of these emissions.

CO_2 Emissions (in Mt CO_2) from Fuel Combustion for Top 6 Emitters Worldwide (2005–2022)



Source: CO_2 Emissions in 2023, International Energy Agency (IEA)

The top emitters are also leading the charge in RE investment. India is prominent in all RE categories, demonstrating its commitment to a diversified RE portfolio. However, despite these efforts, the world is still not on the pathway to keep global warming and average temperature increase below the levels envisaged in the 2015 Paris Agreement.

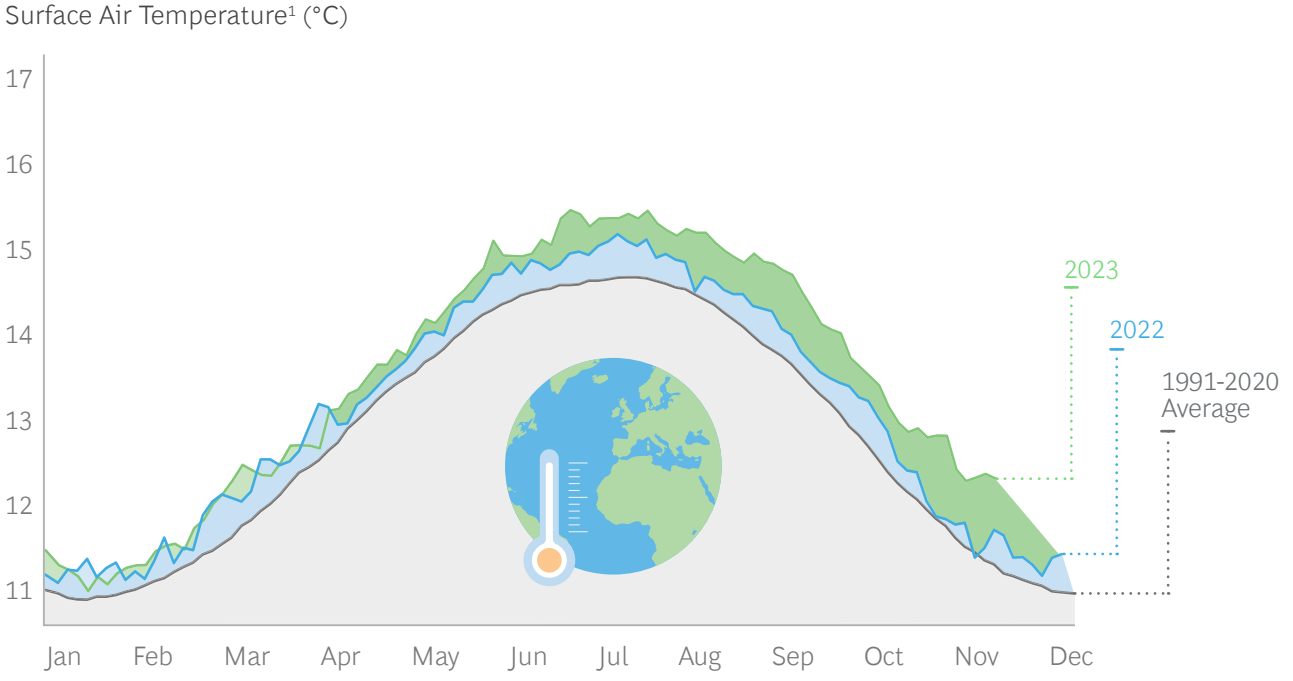
We are not on the Pathway to Limit Temperature Change Below 1.7–1.8°C Yet

To keep global warming below 1.7–1.8°C as a potentially achievable target per discussions in COP29 and other international forums, global greenhouse gas emissions must be reduced by 43% by 2030 compared to 2010 levels and reach net zero by 2050. Achieving this target is challenging at the current pace but remains essential to prevent the most severe impacts of climate change.

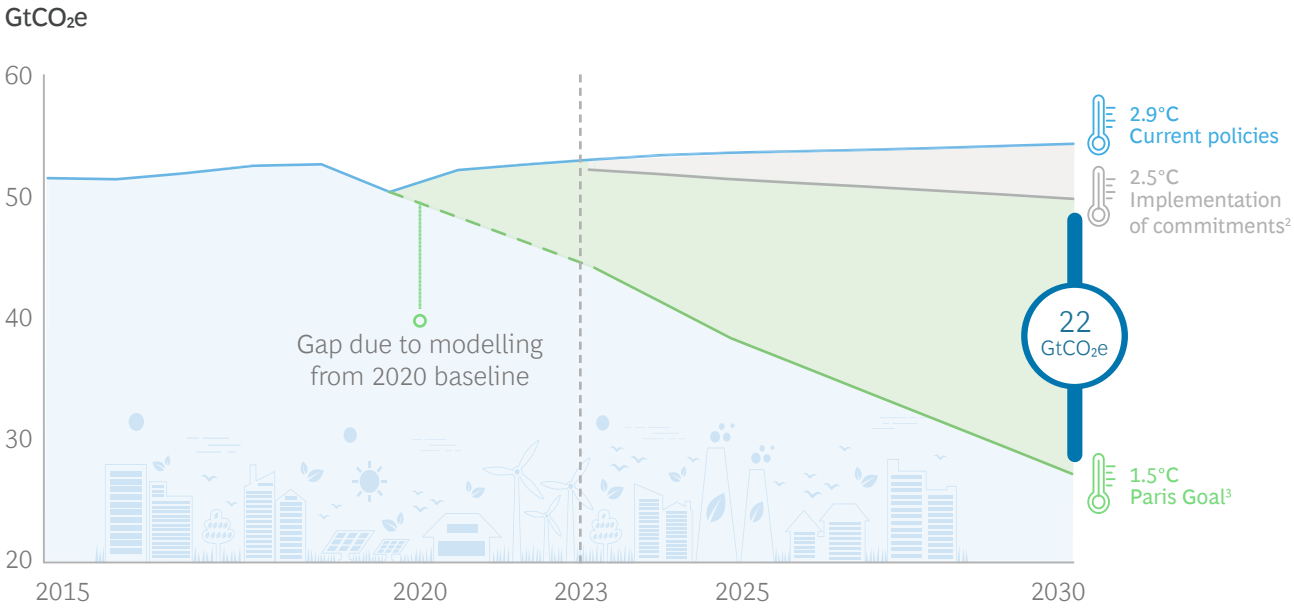
In 2023, the global average near-surface temperature reached 1.46°C above pre-industrial levels, making it the warmest year on record. This rise in temperature indicates that we are significantly off track from the Paris Agreement target.

1. CO_2 Emissions in 2023, International Energy Agency (IEA)

Global Average Temperatures Reached 1.46°C Above Pre-Industrial Levels in 2023



Current Policies put us on Track for 2.9°C



1. Surface Air Temperature refers to temperature measured at 2 meters above the surface; **2.** Based on NDCs submitted to UNFCCC;
3. Modelling conducted from 2020 baseline using projected 2020 emissions.
Note: Emission gap for 2°C pathway estimated to be ~14 $GtCO_2e$ (UNEP Emissions Gap Report 2023).
Source: ClimateReanalyzer.org; Climate Change Institute; University of Maine; Climate Action Tracker, UN Reports, BCG Analysis

At the 28th Conference of the Parties (COP28) meeting held in December 2023, 116 countries signed the Global Renewable Pledge, committing to tripling global RE generation capacity to over 11,000 GW by 2030.

Over 140 countries, including major emitters like China, the United States, India, and the European Union, have committed to reaching net-zero emissions, covering about 88% of global emissions. Countries such as the US, the UK, Japan, and the EU have all set targets for net zero by 2050, while others, like China and India, aim for a slightly later target of 2060 and 2070, respectively.

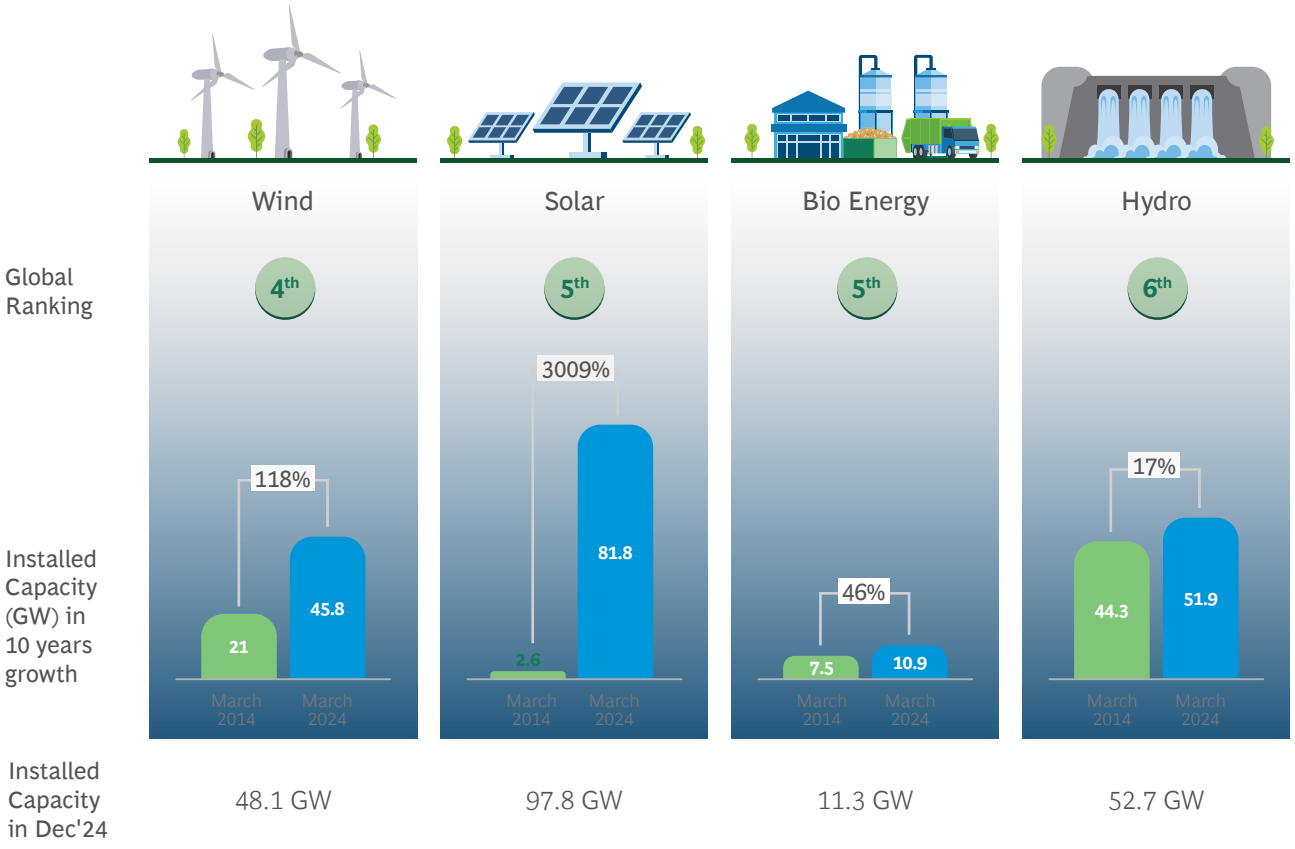
Current decarbonization efforts and policies put the world on track for a 2.5–2.9°C rise in global temperatures, which is far above the Paris Agreement goal to hold it under 1.5°C. Recognizing the urgency for decarbonization, the recent COP29 concluded with requirement for countries to submit their next round of Nationally Determined Contributions in 2025 establishing clear emission reduction target and pathway for 2035.

India is Leading the Energy Transition by Achieving its Targets Ahead of Schedule

India has emerged as a global leader in energy transition demonstrating a strong commitment to reducing its carbon footprint and advancing RE on a massive scale. India's first Nationally Determined Contribution (NDC) in 2015 set two key targets for 2030: to reduce emissions intensity of GDP by 33–35% compared to 2005 levels and to have 40% of electricity capacity coming from non-fossil sources. Remarkably, India announced achievement of both these targets in 2023, nearly seven years ahead of schedule.

India's efforts to ramp up its Renewable Energy (RE) capacity over the last decade has successfully led to India having the 4th largest installed RE capacity globally (in 2023) standing at ~181 GW as of Dec 2023—this has increased to ~209 GW as of Dec 2024. India leads in terms of installed RE capacity across multiple technologies.

India's Installed RE Capacity across Technologies (2014-2024)



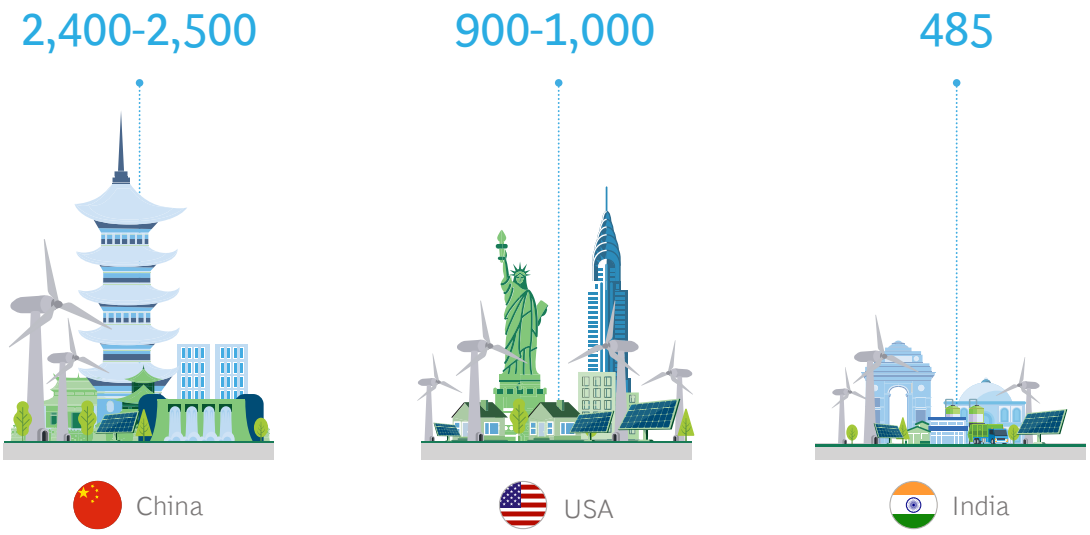
Source: International Renewable Energy Agency (IRENA), Central Electricity Authority (CEA)

In a testament to its commitment towards sustainable development, India revised its Nationally Determined Contributions (NDC) in August 2022, embracing even more ambitious goals for 2030 after achieving its initial targets ahead of time. The revised targets include reduction of emissions intensity of GDP by 45% from 2005 levels and having 50% non-fossil fuel installed electricity capacity.

The 50% non-fossil electricity capacity translates to 500 GW non-fossil fuel installed capacity with target for 15 GW Nuclear & 485 GW RE capacity by 2030. So far, India has demonstrated a promising trajectory for RE installed capacity—In FY23–24, India added 18.5 GW of Renewable Energy capacity, up from 15.3 GW RE additions in FY23 and 14 GW RE additions in FY22.

By 2030, India is poised to emerge as a global leader in Renewable Energy, achieving the world's third-largest total installed RE capacity, following only China and the United States.

Top 3 Countries' RE Capacity Targets for 2030 (in GW)



Note: Excludes 15GW of Nuclear Energy Target
Source: 2030 Global RE Target, Ember Climate

1.2

Journey Ahead and Role of Electricity

Electricity would play a Crucial Role in Decarbonizing Multiple Sectors

In the year 2022, the power sector made up ~40% of global energy-related CO_2 emissions, making it the largest contributor. This is followed by the industrial sector contributing ~25% and transportation contributing ~20%[2]. These sectors are responsible for significant global emissions, prompting countries to develop comprehensive strategies to decarbonize their economies.

Decarbonizing electricity is a pivotal step in achieving global climate targets with benefits extending beyond reduction of power sector emissions to transportation and industry via green electrification. By decarbonizing the electricity system and electrifying use cases in industry and e-mobility, we can target up to ~55–65% of India's total emissions.

2. CO_2 Emissions in 2022, IEA, 2023



02

Transitioning the Electricity System

2.1

Key Implications for Power Systems

As India's energy demand continues to rise in tandem with its economic growth, the electricity system faces a complex challenge: ensuring a continuous and reliable source of power while keeping costs affordable, and simultaneously reducing carbon emissions. Achieving this balance is critical as India transitions towards a green future.

The pressure to avoid power outages in a country with rapidly growing demand means that new capacities must be integrated at an unprecedented scale. If most of this incremental demand is to be met through RE, careful planning must be done to accommodate the inherent intermittency of renewable sources such as solar and wind. This would require significant advancements in grid stability and energy storage solutions to ensure Round-the-Clock (RTC) availability is maintained.

While standalone wind and solar projects are now often cheaper than installing new thermal capacity, the equation shifts when storage is factored in. The intermittency of renewable sources necessitates energy storage solutions to ensure a consistent power supply. While integrating storage can offer stable RE load profiles, it will increase the overall cost of electricity.

We modeled expected demand and installed capacity across various scenarios, considering the 485 GW target. Across multiple scenarios, there are two key implications.

2.1.1 Critical Need for Storage

Under all modeling scenarios, transitioning to a grid dominated by Variable Renewable Energy (VRE) will make energy storage increasingly essential for managing intra-day demand fluctuations—the Central Electricity Authority (CEA) projects a ~336 GWh storage market by 2030.

The need for intra-day storage arises due to the mismatch between peak RE generation (Afternoon in case of India's solar-indexed RE system) versus peak electricity demand in the mornings and evenings. Further, as the share of variable RE in the grid increases, intra-hour generation variability will also be enhanced leading to need for storage to stabilize grid frequency.

However, at a system level, excess electrons will be available for charging only at the mid-day solar generation peak, limiting storage utilization to one cycle per day. On an annualized basis, system-level storage utilization will further dip to 0.6–0.7 cycles, given high variance between peak and non-peak storage demand. Thus, charging & demand constraints together will limit storage utilization making it one of the most expensive elements in the electricity mix.

Battery pack prices have seen a sharp decline over the past year—from $139/kWh pack level cost for Lithium Polymer (LP) batteries, as reported by Bloomberg, in Nov 2023 to lows of $60–65/kWh in Dec 2024, as per Trendforce data.

Large battery capacity in China (>3 TWh) combined with muted demand for EV batteries has led to significant oversupply (2–2.5x demand)[3]—In a bid to offload capacity, manufacturers have slashed margins significantly leading to sharp decline in battery prices.

This trend has been reflected in the tariffs of bids awarded for standalone battery energy storage systems (BESS) in India—**Gensol's winning bid for GUVNL Sep'2024 BESS tender came in at ₹2.62 lakh/MW per month, ~30% lower than its ₹3.72 lakh/MW per month winning bid for GUVNL Jun 2024 tender.**

The recent BESS tenders have prompted many stakeholders to cite a Levelized Cost of Storage (LCOS) at ₹3–3.2/kWh (at 2 cycle utilization) and ₹5–5.3/kWh (at 1 cycle utilization), excluding input power cost and losses, highlighting the growing competitiveness of Solar & BESS for Round-the-Clock (RTC) green power.

3. As per Bloomberg

However, given system-level annual utilization constraints, annualized average utilization for storage assets will likely land at 0.6–0.7 cycles per day. This lower utilization will increase the effective Levelized Cost of Storage (LCOS) to ₹7–8.5/kWh (at current BESS prices), challenging the perceived cost-effectiveness of these solutions.

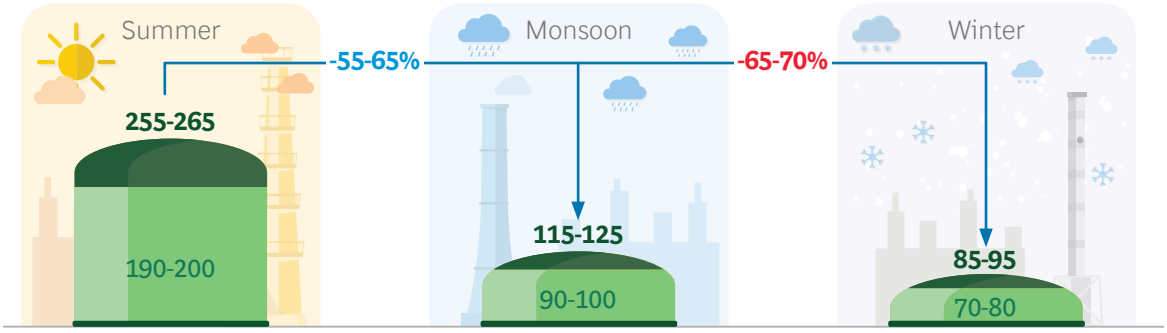
Three key factors drive this:

- **High variation in storage demand across seasons**
  The average daily storage demand in monsoon is projected to be ~50% lower than the average daily demand in summer and ~65% lower than in winter.

- **High variation in storage demand across seasonal peak days**
  The peak day storage demand in monsoon is projected to be 55–65% lower than the peak day storage demand in summer and 65–70% lower than in winter.

Storage demand will also vary across Peak and Non-Peak Days

2030 Storage Demand (GWh)

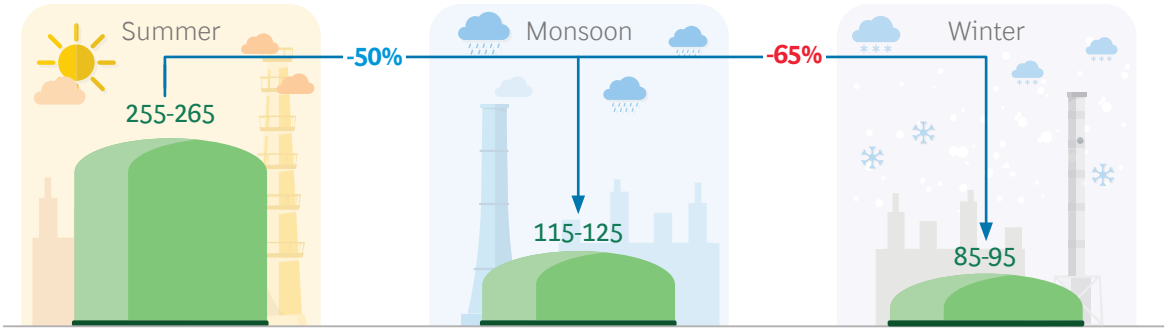


XX: Summer vs. Monsoon peak day storage demand XX: Summer vs. Winter peak day storage demand

Non-peak Demand Peak day demand

Storage demand will vary sharply across Seasons

2030 Storage Demand (GWh)



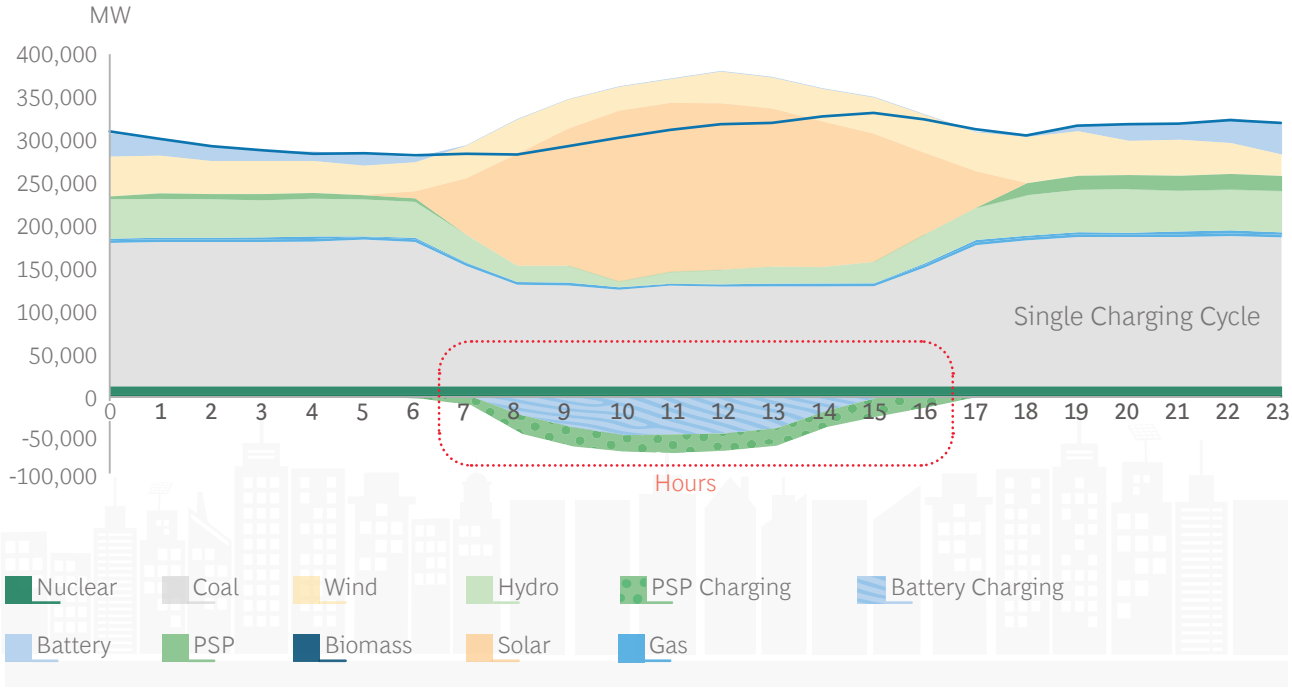
XX: Summer vs. Monsoon storage demand XX: Summer vs. Winter storage demand

Source: BCG Analysis

The combined effect of seasonal and peak day variations results in average annualized storage utilization of 0.6–0.7 cycles.

- **Availability of excess electrons for only one charge cycle per day**
  At a system level, excess electrons will be available for charging only during the afternoon solar generation peak—this caps storage utilization to maximum 1 cycle per day. While individual projects may see higher utilization rates, system level storage utilization will be capped.

Technology-Wise likely Generation Dispatch on Peak Demand Day (2029–2030)



Source: Report on Optimal Generation Mix 2030 Version 2.0, Central Electricity Authority (CEA)

Therefore, at the system level, storage capacity utilization will likely be limited to 0.6–0.7 cycles per day given CEA projected generation capacity mix till 2030, resulting in higher cost.

2.1.2
Need to Optimize Storage Size and Mix

As one of the most expensive elements in the power system, careful sizing is required to maximize utilization of storage as well as the mix between various storage technologies (BESS and PSP).

2.1.2.1
Absolute Sizing for Storage

There are 3 factors which have a significant bearing on absolute storage sizing:

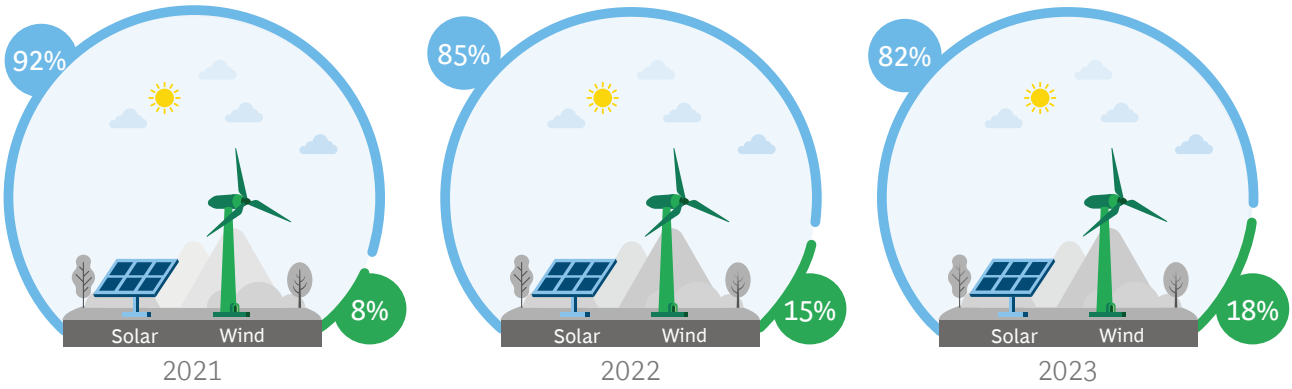
FACTOR 1:
Ensuring the right mix of Solar and Wind

Over the past five years, between 1st April 2019 to 31st March 2024, India added ~10.3 GW of wind capacity and ~52.7 GW of solar capacity[4]— thus, growth in solar capacity is 5x greater than growth in wind capacity. Going forward, balancing mix of solar and wind is critical as for every 1 GW of wind below the planned annual trajectory, 1–2 GWh of increase in storage capacity will be required.

The Government is targeting ~100 GW of wind energy capacity by 2030. As of December 2024, the installed wind capacity stands at 48,163 MW i.e. ~48 GW, leaving a substantial ~52 GW to be deployed. Further, wind installations are more complex than solar, requiring specific wind-rich sites, customized turbines, and technically complex operations and maintenance.

The recent uptick in innovative Renewable Energy tender structures, such as Hybrid, Firm and Dispatchable Renewable Energy (FDRE), and Round-the-Clock (RTC), could promote a more balanced Renewable Energy mix at the point of generation, reducing the reliance on storage. However, it remains crucial to maintain a strong focus on expanding wind capacity.

Share of Solar and Wind in India's RE Capacity Addition from 2021 to 2023 (%)[1]



Source: BCG Analysis based on CEA Installed Capacity Data as of March/December every year

Evacuation availability is a critical enabler for driving wind installations. At several prime RE-locations with both wind and solar potential, solar energy has typically cornered the evacuation connectivity. For example, the Ramgarh Complex, identified by the National Institute of Wind Energy (NIWE) as a wind-rich site with 9 GW of Inter-State Transmission System (ISTS) connectivity, has seen 8 GW of connectivity blocked for solar and only 1 GW of connectivity for hybrid solar-wind capacity. Such patterns of solar projects dominating evacuation capacity in sub-stations close to wind-rich sites across the country has resulted in 50–55% of wind potential in such areas not getting realized.

4. Ministry of New and Renewable Energy (MNRE)
Note: 33% of hybrid capacity is considered as Wind allocation

Approved and Granted Solar/Wind Connectivity across India

all values are in GW units

Name of targeted sub-station	RE Zone	Approved	Connectivity Granted (GW)			Approx. Wind Potential
			Wind	Solar	Hybrid	
Rajasthan						
Fathegarh–Barmer		17.5	nil	15.8	1.7	10.0
Ramgarh complex		9.0	nil	8.0	1.0	5.0
Andhra Pradesh						
Anathapur/Kurnool		12.0	2.2	5.9	3.9	10.0
Madhya Pradesh						
Pachora		4.0	0.7	2.1	1.2	2.0
Madsaur		2.0	0.3	2.0	nil	1.5
Karnataka						
Bijapur		2.0	1.8	nil	0.2	6.0
Koppal & Gadag		14.3	9.3	nil	5.0	7.0
Total (GW)		60.8	14.3	33.8	13.5	41.5
Percentage Allocation			24%	55%	21%	

Wind Potential lost to Solar **54.8%**

Solar Wind

Source: BCG Analysis based on Expert Inputs

The following measures can be considered to ensure that wind capacity does not get crowded out, especially at select high wind speed sites:

- **Dedicated Capacity Allocation for Wind**
  Reserving substations at high-potential wind sites specifically for wind projects may need to be considered. Given the limited availability of wind-rich locations in India, this approach would help prevent the allocation of these valuable sites to other renewable projects, such as solar, ensuring their optimal use for wind energy development.

- **Behind the meter storage installation to optimize substation utilization**
  A concept note from the MNRE highlights sub-optimal utilization of RE evacuation capacity. The Capacity Utilization Factor (CUF) for Solar ranges from 18%–24% with generation peaking to 100% CUF only during peak solar hours. Similarly, Wind CUF ranges from 25–40% with peak CUF typically achieved in the evening and at dawn when wind speeds are at their highest. Thus, there is a potential to reduce required evacuation capacity by locating storage behind the meter, to shave off peak generation—and this can offer potential to add additional generation capacity (especially for Wind at specific high-wind sites). Thus, the MNRE has proposed that solar plants without storage support be mandated to share the transmission infrastructure (for a charge). Further, a minimum annual capacity utilization mandate of 50% is also proposed for all hybrid ISTS connections, effective October 2026.

- **Financial incentives to drive substation capacity sharing**
  At-capacity substations that already support solar energy but are located at wind-rich sites, can be opened up for use by wind projects—with compensation for curtailment losses in case of generation overlap. By encouraging this complementary use of substations, the overall generation profile would better support the grid, enhancing RE integration without needing significant new transmission infrastructure.

FACTOR 2:

"Effective availability" of thermal fleet and natural gas assets

Enhancing existing thermal fleet

Ensuring higher effective availability of existing thermal fleet will be pivotal in optimizing the storage requirement in the system. For every additional GW of thermal capacity (over the existing trajectory of ~6 GW per annum), an estimated reduction of 4–4.5 GWh in storage requirement can be achieved.

However, an effective thermal fleet should come from enhancing availability of the existing fleet rather than creating a greenfield thermal fleet due to two key reasons:

- **Long construction timelines for a greenfield thermal fleet**
  A greenfield thermal power plant can take 4–6 years to be operational—Hence, it will not be able to meet our rapidly increasing storage needs in time.

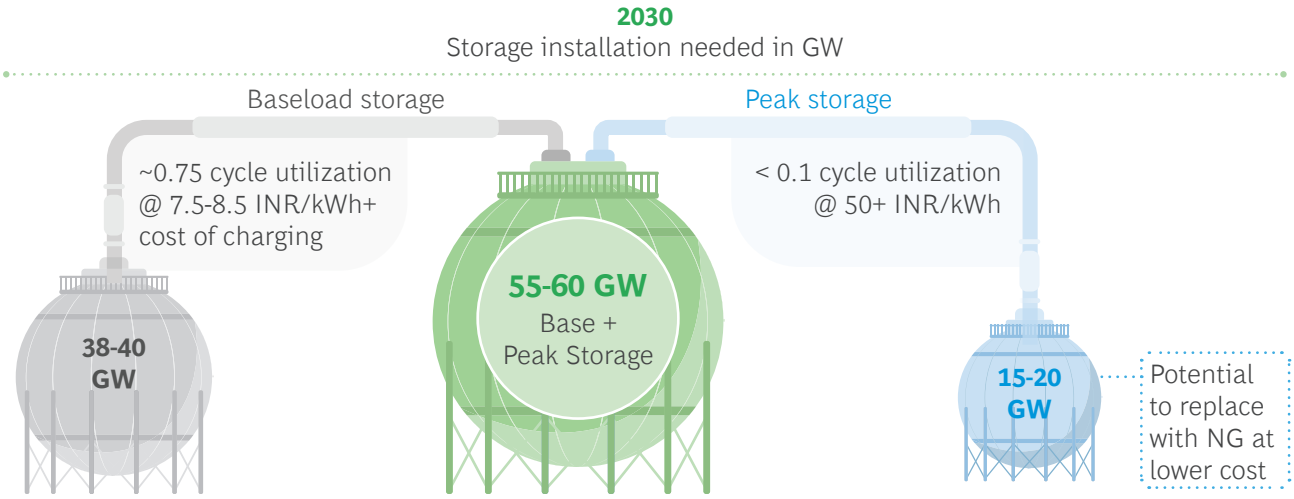
- **High effective LCOE for a greenfield thermal asset**
  If built only for replacing storage, a greenfield thermal asset will have an effective annualized PLF of 10–15% only, leading to effective power cost of ₹35–40/kWh. Practically, however, this will happen via cannibalization of PLF of remaining thermal fleet given the new assets will not be able to be run at less than technical minimum load. Regardless, this will lower utilization of thermal fleet as a whole—thereby, increasing costs.

Therefore, instead of building new capacity, the cost-efficient alternative is to leverage existing C&I captive thermal fleet (~65 GW)[5] to manage peak demand—this capacity is currently lying underutilized as most C&I's have moved towards open access renewables.

Using natural gas assets as peak storage replacement

Storage demand varies sharply across seasons, leading to low utilization (and, therefore, high LCOS) for peak storage. In 2030, there would be potential to replace 15–20 GW of such peak storage with existing natural gas (NG) assets, which would have a lower landed cost.

Leveraging Existing Natural Gas Assets as Peak Storage Replacement can Enhance System Utilization to 70–75% from 50–60%



Note: Assumes system set up for peak hourly storage demand 40-45 GW (Requiring 55-60 GW peak capacity accounting for RTE & flex)
Source: BCG Analysis

Leveraging existing Natural Gas (NG) assets as peaking power plants—particularly during summer months of high demand—can significantly enhance system flexibility and improve the grid's overall utilization. There is potential to leverage existing Natural Gas (NG) assets to complement RE and storage solutions, thereby, improving system utilization by 0.1–0.2 cycles at a grid level.

5. India Climate & Energy Dashboard

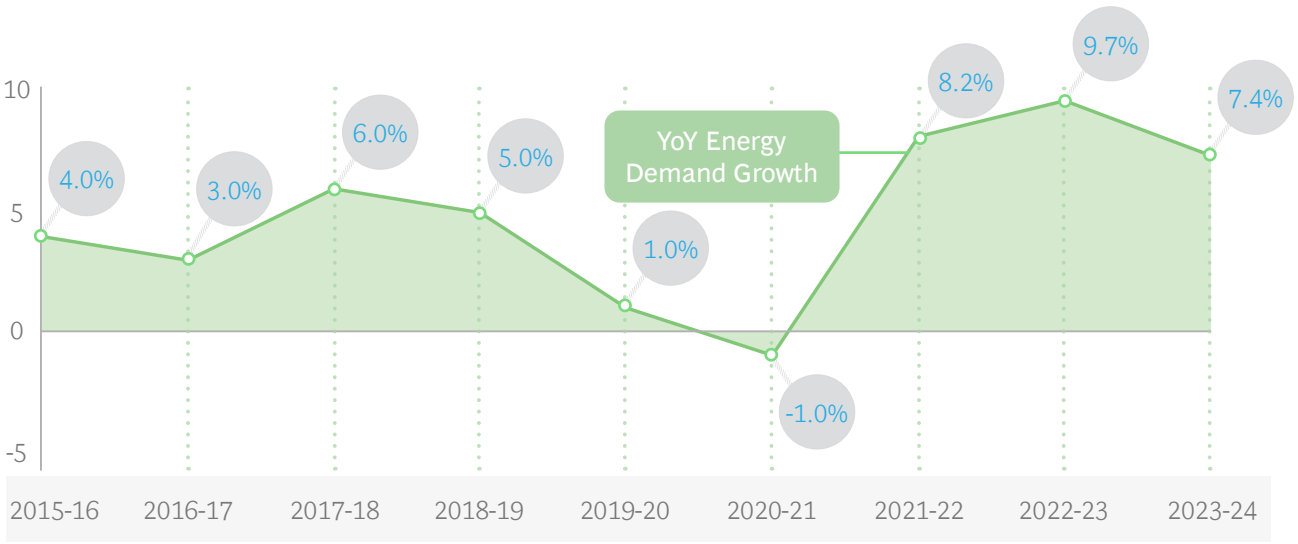
FACTOR 3:

Unprecedented growth in electricity demand

India's energy demand is seeing an unprecedented surge—over the last three years, demand has grown at an accelerated rate, far exceeding historical averages. Even when accounting for the anomalies caused by the COVID-19 pandemic, data shows that since FY21–22, energy consumption has risen at a higher rate than in the pre-pandemic period.

Energy demand grew by 8.2% in FY21–22, 9.7% in FY22–23, and 7.4% in FY23–24. These figures mark a significant uptick compared to the moderate growth rate of around 4–6% witnessed in the pre-pandemic years.

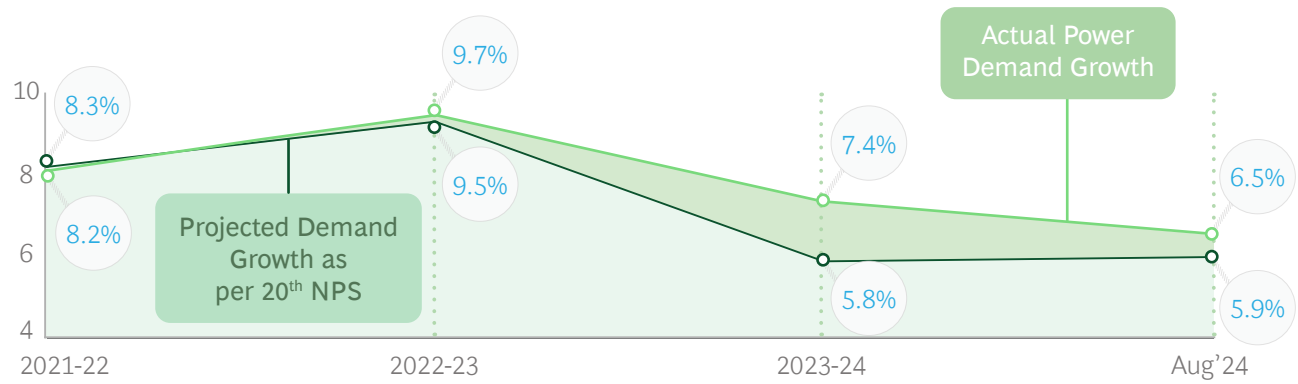
Comparing Energy Demand in India 2015–16 to 2023–24



Source: Central Electricity Authority of India

The predictions from the 20th Electric Power Survey (EPS), which projected moderate growth in electricity demand for FY23–24 and FY24–25 onwards (~6% CAGR), have been outpaced by reality (~7.4% CAGR in FY23–24 and ~6.5% CAGR till Aug 2024).

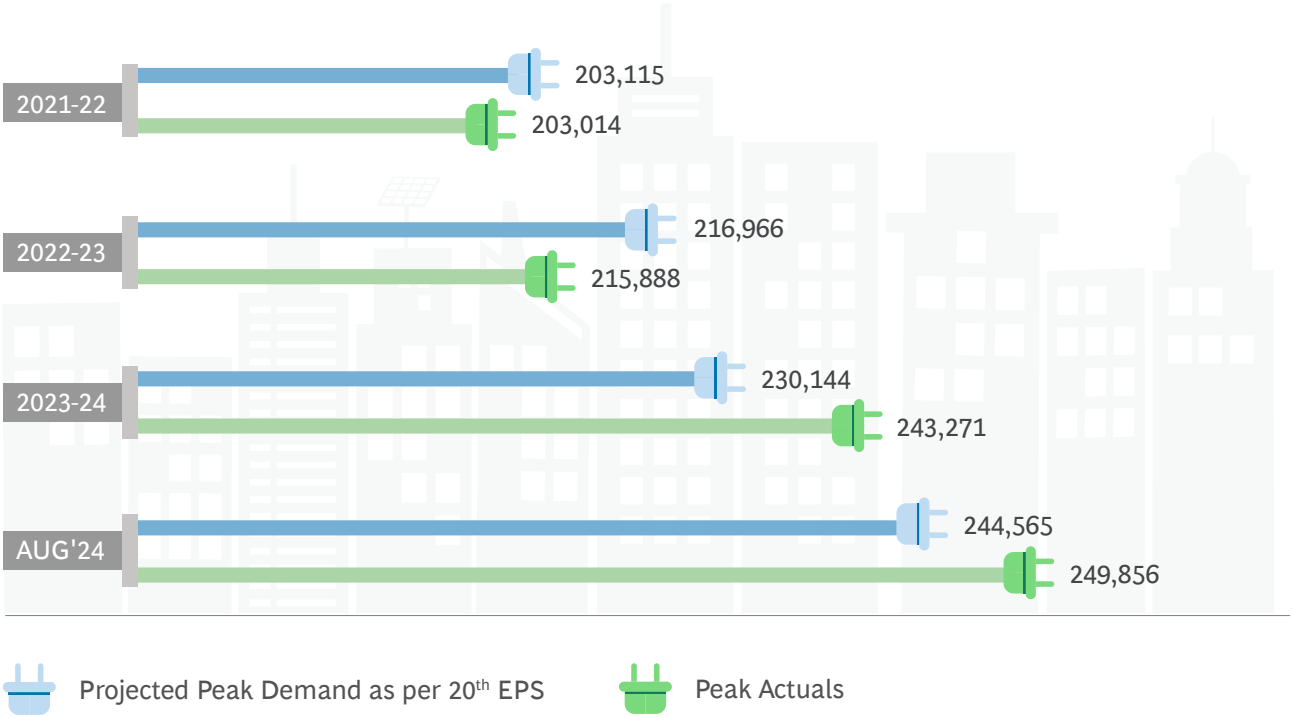
20th EPS Demand Growth Predictions VS Actual Demand Growth



Source: Central Electricity Authority of India

Further, peak electricity demand has also consistently outpaced projections in recent years.

20th EPS Electricity Demand Predictions VS Actual Demand (In MW)



Source: Central Electricity Authority of India

Addressing this surge in demand will also require ramping up storage capacity. For every 1% increase in electricity demand, ~1.5 GWh of storage capacity will be required.

2.1.2.2

The mix of BESS and PSP must be Balanced for Cost and Demand Efficiency in 2030

To determine the optimal balance between BESS and PSP in the 2030 storage mix, it's essential to consider two main factors: the difference in Levelized Cost of Storage (LCOS) between the two technologies and the expected storage demand profile.

- **PSP has a lower LCOS than BESS**
  We have already established that only a single contiguous slot is available for utilization of energy storage systems during the day, primarily during peak solar generation hours, which results in a maximum of 1 cycle per day for **storage systems at** an overall power system level (individual storage assets can of course achieve higher utilization). Therefore, a like-to-like comparison between BESS and PSP would require comparing their costs for the same number of cycles. **Currently, the LCOS of PSP (₹3.6–3.9 for one cycle) is lower than that of BESS (₹5.0–5.2 for one cycle).**

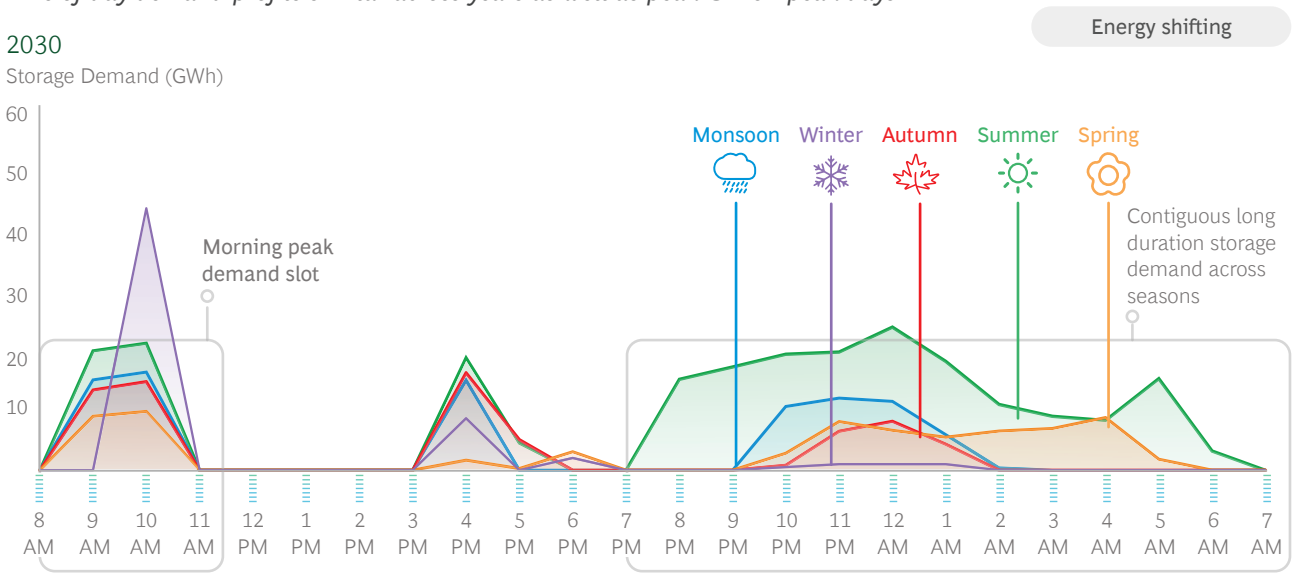
  The primary cost component for PSP is civil works, and PSP projects commissioned today are likely to remain economically viable throughout their lifecycle (40 years+), with minimal cost escalation. Battery prices have substantially declined in recent years, largely driven by a supply surplus; much of the anticipated price reductions have therefore already been realized. In 2023, global installed battery manufacturing capacity reached approximately 3 TWh[6], nearly double the demand that year, resulting in price reductions at the cost of manufacturers' margins. Given already significant margin contraction by manufacturers, further decline in battery prices seems unlikely for the next 3–4 years.

  Any additional decreases will likely occur on a smaller base, primarily within the pack component, which constitutes ~50% of the total pre-tax cost. However, majority of these potential reductions could be offset by depreciation of the Indian rupee against the US dollar. Hence, in rupee terms, PSP is expected to retain a cost advantage over BESS and remain competitive—even in 2030 even in 2030.

- **Storage demand profile favors a higher share of PSP**
  The time-of-day storage demand profile in 2030 is expected to be relatively stable across seasons, with **long-duration storage demand being a consistent requirement. PSP provides a long-duration discharge of 6 hours,** compared to the short-duration discharge of 3 hours provided by BESS, making it the ideal solution for this contiguous long-duration demand and supporting some share of PSP in the mix.

Consistent Need seen for Long-Duration Storage Supports Higher PSP Share

Time of day demand profile similar across years as well as peak & non-peak days

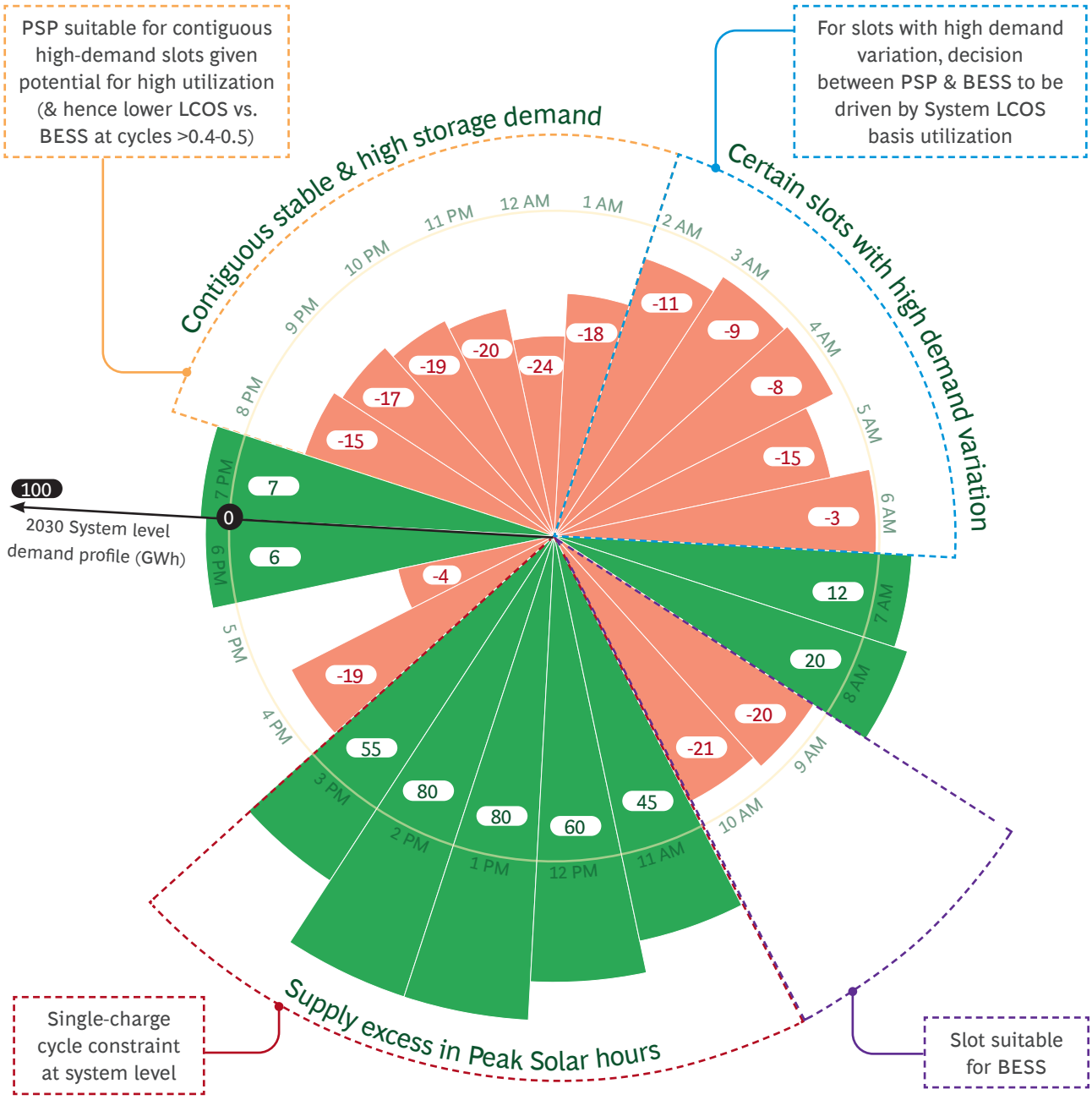


Note: Sizing basis peak days across seasons for 2030
Source: BCG Analysis

6. International Energy Agency, 2024, Batteries and Secure Energy Transitions

- There is a need to optimize storage for two demand slots—a 5–6 hour discharge and a 2–3 hour discharge slot. While PSP is suitable for the longer slot, the decision for the technology used in the shorter slot is driven by the overall system LCOS basis the utilization of both technologies. It is important to note that **PSP would be more competitive than BESS in 2030**, subject to a certain minimum utilization threshold. **Increasing the share of BESS in the mix increases the utilization of both BESS and PSP and a 70:30 PSP: BESS mix yields the optimal storage cost for 2030.**

Only Single Contiguous Slot Available for Charging thereby Capping Cycles at 1 Per Day at a System Level



Note: Sizing basis summer peak day for 2030
Source: BCG Analysis

Key Policy Recommendations to Optimize Sizing and Mix of Storage

Transitioning to a grid dominated by Variable Renewable Energy (VRE) will make energy storage increasingly essential for managing intra-day demand fluctuations.

To optimize storage sizing and therefore achieve optimal system costs, three critical levers need to be addressed:

- **Boost wind capacity especially across wind-rich sites**
  - This in turn requires enhancement of evacuation infrastructure which is a major bottleneck for upcoming wind capacity via
    - Reserving substation/evacutaion infrastructure capacity for wind projects across wind-rich sites for balanced solar and wind development.
    - Installing behind-the-meter storage to optimize evacuation capacity at existing substations, allowing storage during peak power generation hours.
    - Financial incentives for sharing of evacuation infrastructure between solar and wind projects, thereby, leveraging complementary generation profiles.

- **Expand utilization of existing thermal capacity for fast ramp up (~65 GW of existing C&I captive thermal fleet can be leveraged)**

  The Ministry of Power should conduct an assessment of existing under-utilized captive C&I thermal power plants and offer support for refurbishment, modernization & takeover of operations by State owned thermal power entities like NTPC **complementary generation profiles through financial incentives.**

- **Leverage existing natural gas capacity to manage peak demand**

  While we are already seeing peak power tenders being floated for Natural Gas, there is potential to drive accurate forecasting for peak power demand (over and above EPS projections) enabling calendarization of peak power supply tenders for Natural Gas, **offering visibility to developers for operations and procurement.**

Further, power markets need to be developed to capture actual demand-supply patterns offering the right economic inputs to consumers for informed decision-making, such as

- RE Tender structures in formats reflecting true variations in intra-day & seasonal demand; emerging Firm & Dispatchable RE (FDRE) formats are a step in the right direction.
- Market for Storage and trading of ancillary services, which can offer flexible avenues for grid management.

Real-time power pricing or time-of-day pricing can also be explored to shape demand, thereby smoothening the sharp intra-day & seasonal demand peaks. This can be further enhanced.

Pumped Hydro-power Projects can be a critical technology for long-duration storage (6–9 hours), especially for Green Manufacturing and Green Hydrogen sectors. However, PSP capacity installations are currently slow (up to 2–3 years delay reported across certain projects) bogged down by requirement for multiple approvals and fragmented policies at the state level. **There is potential to create a National level body to expedite PSP project approvals, offering clear playbook for project developers and single window clearance assistance.**

2.2

Unlocking Renewable Energy at Scale

Meeting India's target of 500 GW of non-fossil fuel capacity by 2030 will require more than incremental changes. The complexity of integrating large-scale RE, ensuring grid reliability, and keeping costs manageable requires a comprehensive approach across three critical pillars: policy, infrastructure, and financing.

India has already laid a strong foundation with its comprehensive policy frameworks, which have driven RE growth. The country has seen substantial success through policy initiatives to address the demand-side, supply-side and for the overall ecosystem development.

- **Demand-side policy enablers** include the PM Surya Ghar Muft Bijli Yojana, Inter-State Transmission System (ISTS) charge waiver, Green open access rules and Renewable Purchase Obligations (RPOs).
- **Supply-side policy enablers** comprise PPA-based tenders, "Must-run" status for RE, RE Zones/Solar Park Scheme, Launch of GDAM and GTAM, CPSU Generation schemes, and PM-KUSUM amongst others.
- Further, policy action has been undertaken with a view towards **cohesive ecosystem development** such as Green Energy Corridor Scheme, National Green Hydrogen Mission, PLI Scheme for Solar PV & ACC Batteries, and Late Payment Surcharge Rules.

While India's policy landscape is fairly robust, two other vital enablers—infrastructure and financing—require further attention to unlock RE at scale.

On the infrastructure side, the pace of RE deployment is increasingly constrained by land acquisition challenges and transmission infrastructure bottlenecks. Streamlined land acquisition processes and proactive evacuation planning will be crucial, modeled after the success in states like Gujarat and Karnataka. As projects scale up, ensuring sufficient transmission capacity, removing roadblocks related to Right-of-Way (RoW) approvals and addressing the issue of sub-station delays, will be pivotal to maintaining momentum.

Further, the significant financing required to meet India's energy goals—estimated at ₹30–32 lakh[1] crores by 2030—demands an enhanced focus on mobilizing capital. Scaling up financing through green bonds, domestic institutional investments, and international funding will be essential going forward. Empowering NBFCs such as IREDA, PFC, and REC to play a more significant role in financing RE projects and encouraging banks to increase lending to the sector will help bridge the funding gap.

The next phase of India's green journey will depend on addressing infrastructure bottlenecks and securing affordable financing. These pillars will unlock the full potential of RE at scale, ensuring that India remains on track to meet its ambitious targets.

Source: National Economic Survey 2024

2.2.1
Land, Evacuation and Offtake

To achieve India's 2030 targets, over 8 lakh acres of land[7] will be required to set up RE projects across India. While India has ample land available, the real issue lies in the availability of land that is economically attractive for RE developers. Land that is technically suitable for wind or solar farms is not necessarily easy to acquire, particularly in terms of making it financially viable for large-scale RE projects. This constraint stems from the need to identify, aggregate, and secure parcels of land that provide the right balance of cost, accessibility, and proximity to infrastructure—factors that significantly influence project feasibility.

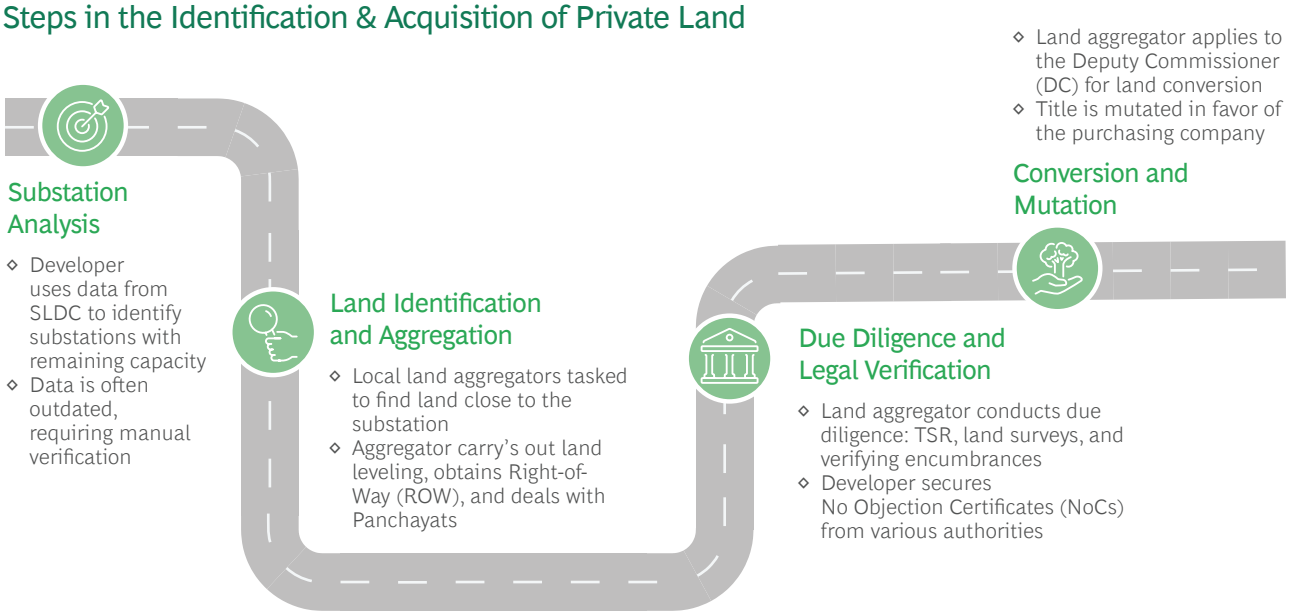
Additionally, without augmenting the current grid infrastructure to evacuate and transport RE, India's 2030 targets will remain out of reach. Given the ongoing delays in commissioning evacuation and transmission infrastructure, **urgent proactive measures** are essential to ensure the grid can support future renewable energy capacity.

While the government's 50 GW annual bidding calendar over FY24–28 significantly sped up bidding activity in the sector, offtake has not kept commensurate pace. As per the Hindu BusinessLine report published in November 2024, of the 357 renewable projects bid between April 2022 & October 2024 with cumulative 95 GW capacity, PPAs are yet to be signed for 224 projects with 55 GW capacity translating into a PPA rate of only ~42% (on a capacity basis).

Even with ~174 GW of renewable energy projects in pipeline (with ~45% capacity already under construction), new capacity is being bid-out - leading to significant supply overhand, while DISCOMs seem inclined towards a "wait and watch" approach given the financial and regulatory uncertainty. With the growing success of open access model for Commercial & Industrial (C&I) segment, DISCOMs face growing demand uncertainty from their largest and most profitable segment. Further, declining Renewable Energy prices and proposed replacement of 25-year PPA structure with 15-year structure is leading DISCOMs to postpone signing of PPAs or negotiate heavily on tariffs.Ensuring sustained offtake will be critical to maintaining the trajectory towards achieving the 500 GW target by 2030.

Private Land Acquisition

Steps in the Identification & Acquisition of Private Land



Source: BCG Analysis

7. Press Information Bureau. Government of India. In press. Year End Review 2024 of Ministry of New & Renewable Energy

Government Land Acquisition

The process for acquiring government land follows a similar but often more cumbersome pathway. Developers must apply through the State Nodal Agency (SNA), after which the District Magistrate (DM) verifies the land's status through local authorities like the Patwari and Tehsildar. For larger plots, approval from the state cabinet may be required, which can take several years due to bureaucratic inefficiencies and the involvement of multiple layers of governance. **The Department of Revenue is responsible for handling land records, ownership verification, and land-use conversion.**. Depending on the type of land, land-use conversion from Agricultural to Non-Agricultural land may also be required.

Government land is significantly cheaper than private land, but approvals are notoriously slow, and applications are rarely accepted. States like Gujarat have successfully streamlined these processes, making it easier for developers to acquire government land.

Challenges Faced by Developers



Outdated Data
Data from SLDC is often outdated
Manual verification adds time and cost to the process



Fragmented Land Ownership
Private land is highly fragmented
Negotiation with multiple landowners, increasing cost and complexity of acquisition



RoW and Transmission Lines
Right-of-Way (RoW) approvals are difficult to secure
Lengthy negotiations with local Panchayats causes delays and increase costs due to consensus needed among local stakeholder



Bureaucratic Inefficiencies
Navigating multiple layers of approvals, especially for converting agricultural land
Developers frequently encounter slow approvals from local authorities



Regulatory Approvals
Converting agricultural land to industrial
NoC requirements from pollution control boards and local authorities further compounds delays

Source: BCG Analysis

Whether private or public, the process of acquiring land is often complicated by legal, complicated and logistical hurdles that significantly impact project timelines, costs, and overall feasibility. These challenges can vary from state to state, depending on regulatory frameworks, local governance structures, and land availability. While some states have made significant strides in streamlining these processes, others continue to face obstacles that developers must carefully navigate.

Leading RE developers were surveyed to score states on key land acquisition-related parameters, with scores ranging from 1 (most favorable) to 5 (least favorable). The following table captures the mean scores for each parameter across states:

Mean Scores for States for Efficiency of Land Acquisition Process
(1 is most favorable, 5 is least favorable)

Parameter	AP	GJ	KN	MP	MH	RJ	TN	TG	UP
Land policy availability	2.7	2.0	2.7	2.5	2.7	1.7	4.0	4.5	3.0
Land policy implementation	3.0	1.7	2.7	4.0	3.3	1.3	4.5	4.5	3.0
Land availability	2.7	1.7	2.7	3.0	3.0	1.7	4.0	4.5	3.0
Land conversion	3.0	2.0	3.0	2.5	3.0	1.0	4.5	3.0	2.5
Overall	**2.8**	**1.8**	**2.8**	**3.0**	**3.0**	**1.4**	**4.3**	**4.1**	**2.9**

AP - Andhra Pradesh,
GJ - Gujarat,
KN - Karnataka,
MP - Madhya Pradesh,
MH - Maharashtra,
RJ - Rajasthan,
TN - Tamil Nadu,
TG - Telangana,
UP - Uttar Pradesh

States: Leading in Land Acquisition Efficiency

Best Practices

Rajasthan

- Facilitates the allocation of government land at concessional rates, especially for large solar parks.
- Streamlined process for converting land to industrial use
- Green category classification for Renewable Energy projects

Gujarat

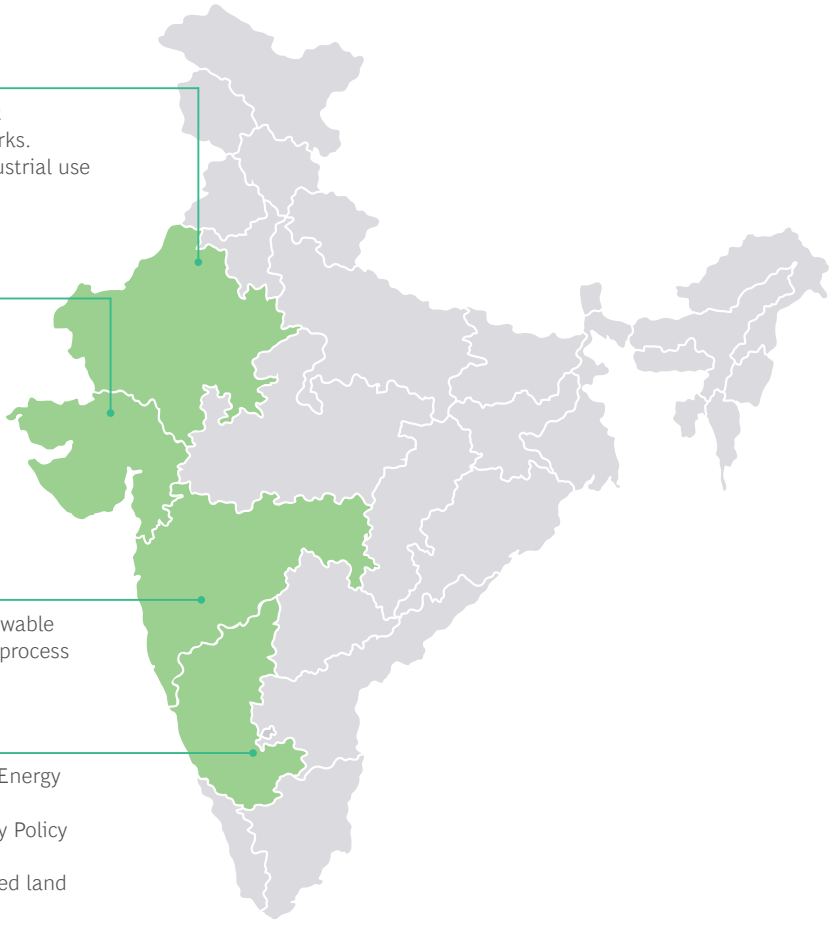
- National leader in land procurement for Renewable Energy projects.
- Robust and transparent framework for acquiring both private and government land
- Land bank system outlining pre-aggregated land for the setup of RE projects
- Clear documentation processes, and efficient bureaucratic handling

Maharashtra

- Strong regulatory framework surrounding Renewable Energy, offering clarity in its land procurement process for RE projects

Karnataka

- First state to allow open access for Renewable Energy in 2017, setting a precedent for other states.
- Updated and comprehensive Renewable Energy Policy (2022–27)
- Facilitates land procurement by allowing deemed land conversion for Renewable Energy projects.



Source: BCG Analysis, Expert's, State RE Policies, State Revenue Dept Policy, Industrial Policy

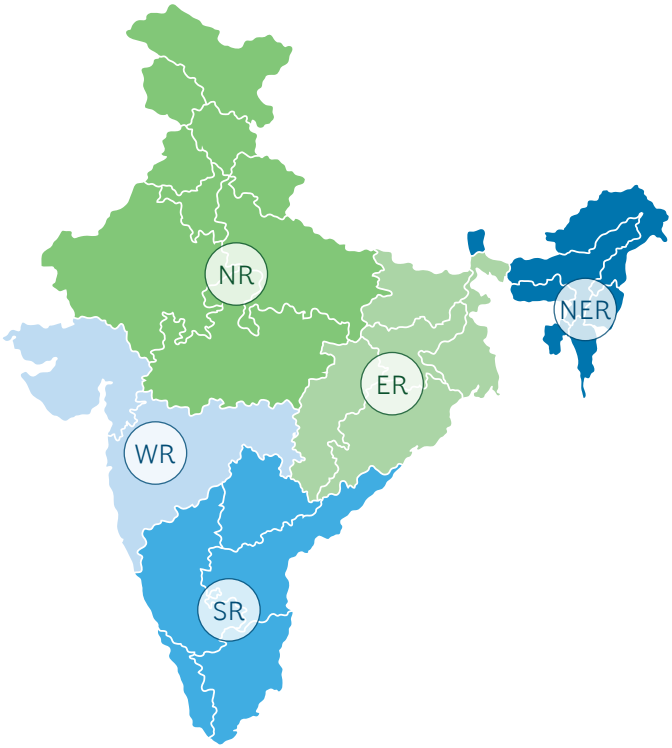
Substations Experience Delays, which Vary Significantly Across Regions

India's current grid infrastructure is struggling to support the surge in renewable capacity addition. Developers are reporting delays in grid connectivity, with evacuation systems for many upcoming projects expected by 2029 at the earliest, as reported by IndianExpress. Further, 18 major projects managed by the Power Grid Corporation of India, totaling approximately ₹30,000 crore, is experiencing delay of up to 32 months.

According to Central Transmission Utility of India Limited (CTUIL) petition data, approximately **50 GW/GVA** of substation infrastructure projects had petitions filed against them, citing delays in their commissioning. Furthermore, infrastructure delays vary significantly across regions of India, with certain states bearing the brunt of these delays.

Region-wise Delayed Substation Infrastructure

Region	Delayed Capacity (GW)	Average Delay (months)	Max Delay (months)
NR	19	~10	24
ER	~0	3	3
WR	15	~15	21
SR	12	~11	15
NER	0	NA	NA



Note: Delayed capacity is the capacity of substations' that are facing delays in erection or upgradation and does not necessarily capture the entire current pipeline
Source: Central Transmission Utility of India Limited (CTUIL) petition data

Source: Union Statistics Ministry

Leading RE developers were surveyed to score states on the availability of evacuation infrastructure, with scores ranging from 1 (most favorable) to 5 (least favorable). The following table captures the mean scores across states:

Mean Scores for States on Evacuation Availability
(1 is most favorable, 5 is least favorable)

Parameter	AP	GJ	KN	MP	MH	RJ	TN	TG	UP
Evacuation availability	2.3	1.5	2.0	3.0	3.0	1.8	3.0	3.5	3.0

AP - Andhra Pradesh,
MP - Madhya Pradesh,
TN - Tamil Nadu,

GJ - Gujarat,
MH - Maharashtra,
TG - Telangana,

KN - Karnataka,
RJ - Rajasthan,
UP - Uttar Pradesh

Source: BCG Analysis basis survey

Delays are Primarily Due to Issues with Right-of-Way (RoW) Issues and Land Approvals

The root causes of these delays primarily include:

- **RoW Issues (flagged by 55% of developers surveyed)**
  RoW concerns represent over half of the reported delays. A potential mitigation strategy could involve expanding wind energy projects in regions with established solar plants to utilize existing transmission infrastructure more efficiently.

- **Land Approvals and Construction Delays (flagged by 18% of developers surveyed)**
  Lengthy regulatory approval processes and construction challenges contribute to a smaller but notable share of delays.

Modelling the Impact of Available Policy, Land Acquisition Process, and Evacuation Infrastructure on Installed RE Capacity

A curve-fit analysis conducted on the Renewable Energy (RE) transition of nine Indian states provides significant insights into how land acquisition and energy infrastructure impact the ability of states to meet the RE capacity targets for 2030.

We focused on three critical areas for evaluating the impact on installed capacity: state RE focus, land acquisition ease, and energy infrastructure.

Key Findings

- **State RE Focus[8]**
  This dimension evaluated whether the state had relevant RE policies, if RE was a priority sector, and if other administrative and regulatory mechanisms supported RE development. Despite its significance, the curve fit indicated that having a strong policy focus alone did not significantly impact RE installation capacity. This is due to the ground reality that policy implementation can be slow, leading to project delays. Developers corroborated that these practical challenges, especially in the absence of smooth policy execution, can undermine otherwise strong RE policies.

- **Land Acquisition Ease[9]**
  This factor examined how streamlined the land acquisition process was. It included parameters such as the availability of land banks, agriculture-to-non-agriculture land conversion, and exemptions for stamp duty and pollution clearances. The analysis showed that this factor significantly impacted installed RE capacity. If states where RE capacity is to be installed to meet 2030 goals do not streamline acquisition processes, we risk falling short of our target installed RE capacity by ~60 GW. This highlights the need to simplify land acquisition processes to unlock higher RE growth.

- **Energy Infrastructure[10]**
  This criterion focused on incremental energy capacity and the development of transmission infrastructure necessary to evacuate the generated power. The analysis showed that adding 1 GW of evacuation infrastructure led to a 0.42 GW increase in installed solar/wind capacity, indicating that states with robust energy infrastructure are more likely to meet their RE targets.

Future Outlook

According to Trendline Analysis, India's ability to meet its 2030 RE targets hinges on two critical factors: timely infrastructure development and streamlined land acquisition processes. As per the National Electricity Plan II (NEP-II), the government aims to install 783 GW of substation infrastructure between 2024 and 2030, enabling the evacuation of 283 GW of additional wind and solar capacity across several states, including Rajasthan, Gujarat, Ladakh, and Tamil Nadu, among others. This capacity is essential for achieving India's RE goals. However, two main risks could significantly derail this progress:

- **Infrastructure Delays**
  Delays in setting up the necessary substation infrastructure would limit the ability to transmit the additional RE capacity to the grid.

- **Land Acquisition Challenges**
  State governments with restrictive land acquisition policies pose a significant hurdle for RE developers. Without reforms to ease land acquisition, this issue could cause substantial delays in RE project implementation.

8. State RE Policy, State Industrial Policy; **9.** Experts, State RE Policy, State Rev Dept Policy State Industrial Policy;
10. BCG Analysis, NEP-II, CEA, Niti Aayog

Potential RE Capacity Gaps Under Different Infrastructure and Land Acquisition Scenarios

Scenario Analysis	Shortfall Against Target RE Installed Capacity (GW)	
	Current Land Procurement Ease	Increased Land Procurement Ease
100% of Infra by 2030	Shortfall of 0–60 GW	Surplus of 20-60 GW
90% of Infra by 2030	Shortfall of 30-90 GW	Surplus of 30-0 GW
80% of Infra by 2030	Shortfall of 70-130 GW	Shortfall of 0-30 GW

Source: BCG Analysis

Summary of Findings

- A 10% shortfall of generation evacuation infrastructure may result in a ~30 GW shortfall in RE installations, ceteris paribus.
- An increase in land acquisition ease across RE-rich states (AP, TS, TN, etc.) can result in ~60 GW of additional RE installations, ceteris paribus.

Key Policy Recommendations to Expedite Land, Evacuation and Offtake for RE Projects

Land identification & acquisition can be streamlined by considering 4 key initiatives to provide policy clarity to developers as well as expedite approvals:

- States can publish their **land acquisition playbook** with transparent and clearly documented frameworks for acquiring or leasing government as well as private land. Up-to-date state level playbooks can be hosted on a national-level online portal for quick access by developers. Further, via the online portal, developers can be connected with district-level task forces which offer on-ground support in land document verification and processing, as land is a very-much a state subject and thereby requires local validations & approvals.

- States can implement efficient **"deemed land conversion"** policies, which automatically classify wasteland or non-agricultural lands for renewable use and have no additional associated costs, expediting approvals.

- Intense demand is driving up land prices in solar-rich states (e.g., Rajasthan, Gujarat, etc.) and at high wind-speed sites (e.g., Tamil Nadu) leading to corresponding increase in project cost. However, rapidly declining solar module prices as well as increasing Plant Load Factor (PLF) for newer module technologies presents an opportunity for lower-solar irradiation states to package themselves as an attractive venue for RE developers. **A National-level study can be conducted to create a view on relative levelized cost of electricity across states considering land cost, irradiation level, ease of approvals etc. to pinpoint RE-friendly states as well as consider feasible financial & non-financial incentives which can offered to level the playing field.** By fostering healthy competition across states, this measure will also create incentives for states to streamline their land acquisition and other RE-related policies.

- **Government-led RE land acquisition & transmission RoW** can significantly reduce timelines for project developers. State-level nodal offices can be established to act as a land aggregator, identifying and acquiring private land parcels for developers. They can coordinate with other government departments (including the Ministry of New and Renewable Energy, State Renewable Energy Departments/Agencies, the Revenue Department, the Ministry of Environment, Forest and Climate Change (MoEFCC), State Transmission Utilities (STUs), Local Municipal Authorities, etc.) to ensure fast and accurate data collection, reducing delays and improving the overall process.

Availability of grid infrastructure can be expedited by actions across 5 key aspects

- Low preparedness and planning have aggravated grid infrastructure constraints. It is essential to **synchronize transmission capacity planning at a national level** incorporating accurate forecasting of state-wise electricity demand basis projected electrification trends vs. simplistic demand estimation assuming power growth at historical rates. Further, given lengthy RoW approval timelines, transmission capacity development needs to operate at a minimum 2–3 years lead time to RE capacity installation.

- In addition, **national-level digitized tracking systems** can be employed to
  - Provide up-to-date view on available substation capacity, thereby optimizing utilization of currently available capacity.
  - Monitor upcoming capacities across generation & transmission infrastructure for effective planning.

- Increasing global demand driven by RE expansion and limited number of players has led to a supply bottleneck for transmission equipment—for instance, lead time for transformer delivery has reportedly increased from 9 months to 14 months. In the short term, **aggregated order placement across developers, enabled by central auctioning agencies, can drive higher bargaining power for Indian developers with global suppliers.** Further, behind-the-meter battery augmentation can be explored as an interim solution at high load sites to enhance evacuation capacity. Transmission equipment will continue to be under pressure as grid expansion and replacement ramps up globally with increasing thrust on renewables and grid modernization. This presents **an opportunity for ramping up domestic transmission equipment manufacturing industries with targeted support (e.g., import support for key raw materials).**

- **Private player participation in transmission should be encouraged** to ensure sector competitiveness and bandwidth for project execution. These projects can be run in Public Private Partnership (PPP) mode with the State nodal body supporting in approvals while the developer anchors the project execution.

- Currently, states have limited direct financial benefits from setting up ISTS projects. Beyond capital investments and job creation, states do not generate significant revenue because electricity duty is levied in the consuming state, and waivers on conversion and stamp duties are often provided to attract developers. A marginal trading fee system similar to the model used by the Solar Energy Corporation of India (SECI) could be enacted to address this. Under this system, **states supplying energy for ISTS could earn a small fee per unit of energy transmitted (e.g., ₹0.07/kWh, as applied in SECI tendered projects), thus providing a direct financial incentive for their participation.**

Policy initiatives incentivizing DISCOMs to sign Renewable Energy PPAs

- DISCOMs are currently delaying signing of offtake due to expectation of further decrease in RE tariffs with declining module prices. One measure to dis-incentivize this behavior can **be implementation of the Uniform Renewable Energy Tariff**, proposed by the Ministry of Power, which enables implementing agencies to blend tariffs across bids into a uniform rate for DISCOMs, negating the possibility of bid-level price negotiations by DISCOMs & removing the incentive for DISCOMs to wait for lower bids.

- Further, **adherence to Renewable Purchase Obligations (RPO)** can be strengthened by imposing stringent penalties for non-compliance, tallied on a quarterly basis. As per provisional data presented in a circular issued by the Ministry of Power on 1st August 2023, 19 States & UTs did not meet mandated RPOs for FY22–23.

2.2.2
Green Financing

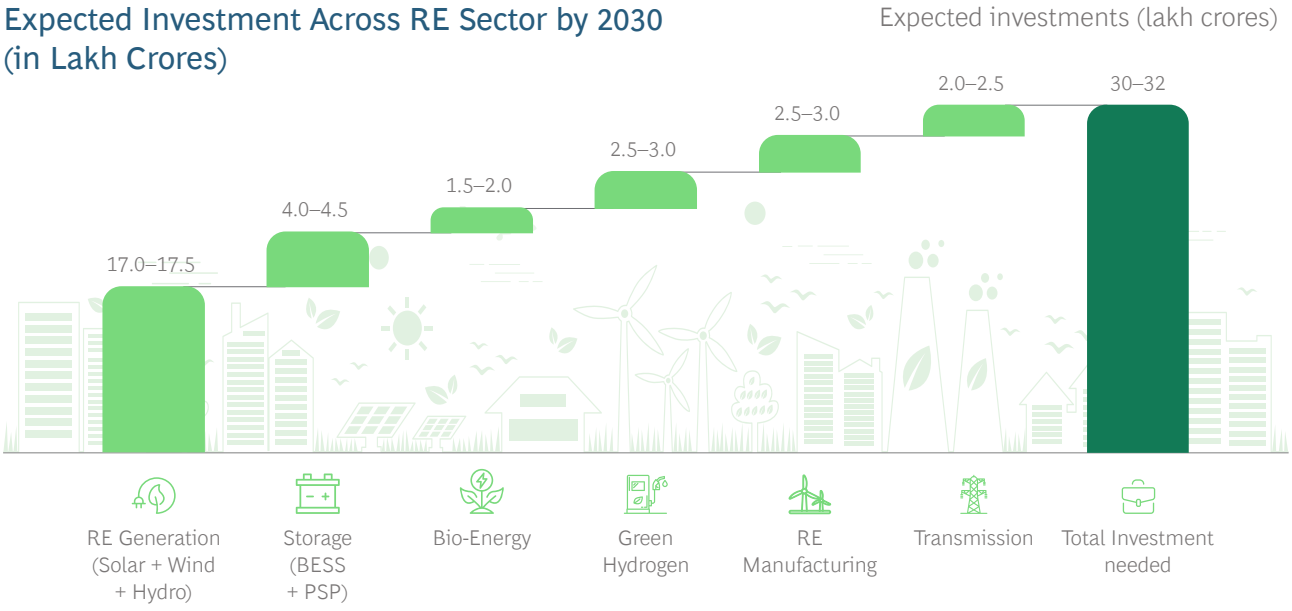
Financing India's Path to Meet 2030 Ambitions

One of the key factors influencing the cost of RE projects is financing costs, which account for approximately 30–35% of the Levelized Cost of Energy (LCOE) in sectors such as solar and wind. This makes the cost of finance a key determinant in keeping the price of RE competitive and accessible.

Green financing has been a contentious topic globally with Developing countries requesting greater contribution from Developed countries given their higher historical contribution to per capita carbon emissions—as per data from Carbon Brief & World Resources Institute, Developed nations such as US, Russia, Germany, UK, Japan and Canada comprise ~10% of the world's population but have contributed to ~39% of cumulative carbon emissions in sharp contrast to Developing countries such as India, China, Brazil and Indonesia which comprise ~42% of world population but have contributed to only ~23% of cumulative emissions. **In the recent COP29, Developed countries committed to $300 Bn fund annually by 2030 vs. ~$1,300 Bn required by Developing nations**. Against this backdrop, it is imperative for Developing nations to look beyond climate support, towards financing from private global and domestic sources, to ensure that their climate finance needs are adequately met.

To meet India's ambition of achieving 500 GW of installed capacity from non-fossil sources by 2030, an estimated investment of ₹30–32 lakh crores will be required. India must focus on green financing to meet these ambitious decarbonization and energy transition goals.

Expected Investment Across RE Sector by 2030 (in Lakh Crores)



Based on the above estimation, RE Generation will lead investment demand with 55–57% of total investment—Within RE generation, solar generation will require largest investment ~67% of overall RE generation.

Going forward, storage will be a critical component for reliable energy supply and grid stability—requiring ~₹4.0–4.5 lakh crores over the next 6 years i.e. ~15% of the total investment required across the RE sector. Additionally, investment in development of Green Fuels (Bio-energy and Green Hydrogen) to the tune of ~₹4–5 lakh crores will be required to decarbonize industrial sectors.

Key enablers for the clean energy transition—Transmission & RE equipment manufacturing will also require substantial support with ₹4.5–5.5 lakh crores in investments till 2030.

To finance our goal, ~75% of investment is expected to come from debt (₹22–24 lakh crores) and ~25% from equity (₹6–8 lakh crores). This projected requirement is nearly 8 times the investment from 2014 to 2023, highlighting the significant scale-up needed in the coming years.

Source: National Economic Survey 2024

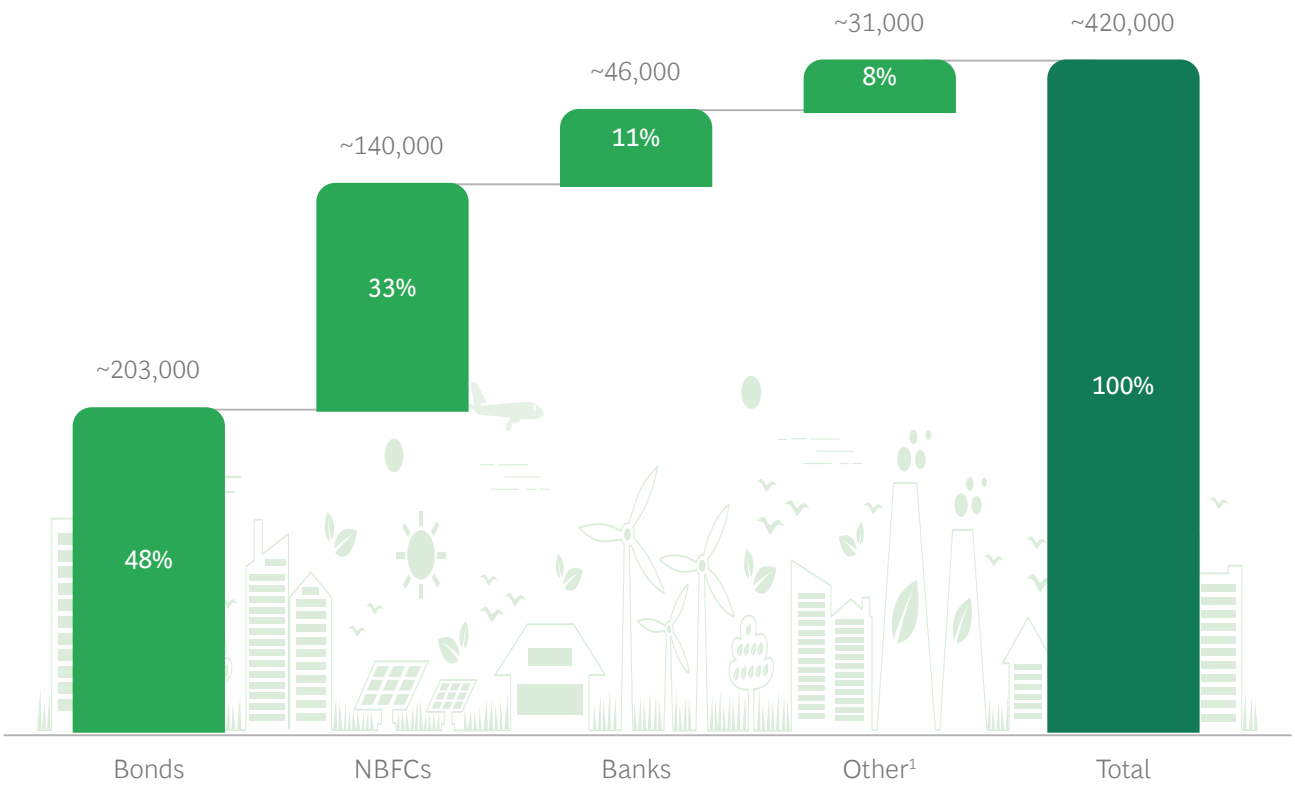
India’s RE Financing over the Last Decade

It is estimated that over 2014 to 2023, investment in India's renewable sector totaled ₹6.6 lakh crores. ~30% of this investment came in the form of equity and grants while the remaining ~70% came in the form of debt.

As of 31st March 2023, the outstanding debt for the RE sector stood at ₹4.2 lakh crores.

Most of this funding is via bonds, which comprise 48% of the total debt (40–50% bonds issued overseas while rest issued in Indian markets), followed by project lending by NBFCs at 33%. Banks and other sources contribute smaller shares, at 11% and 8%, respectively.

Split of Debt Outstanding for RE Sector as on 31st March 2023 by Source (in INR Crores)



1. Includes Other banks, DFI Project funding etc.
Source: BCG Analysis

Key Policy Recommendations to Drive RE Financing across Funding Sources

Mobilization of global funds towards India's RE sector will be critical to meet the large quantum of financing requirement; 3 key measures can be considered:

- With increasing climate awareness, institutional investors are facing pressure from shareholders & regulators to take cognizance of the ESG impact of their investments. Currently, there are 220 signatories to the Net-Zero Asset Managers Alliance with a combined $57 Tn AUM. This presents an opportunity for India to position itself as an attractive "green" investment venue by **adopting a clear definition and "Green" taxonomy or classification system for environmentally sustainable economic activities,** helping investors easily and accurately identify green investments (mitigating risk of "green-washing") and expedite sustainability-linked disclosures.

- There are various Global DFIs which have a high commitment in Asia but remain relatively under-indexed in India, such as the French Development Agency, Green Climate Fund, Department for International Development, etc. **Government led reach-out can potentially enhance awareness of India-based opportunities for these DFIs,** enhancing flow of concessional, long-term finance to India.

- **Removing or reducing the withholding tax on foreign-currency bonds floated by Indian RE developers or RE financing institutions** can be a strategic move to attract global investors, which would help boost foreign investment and deepen India's bond market.

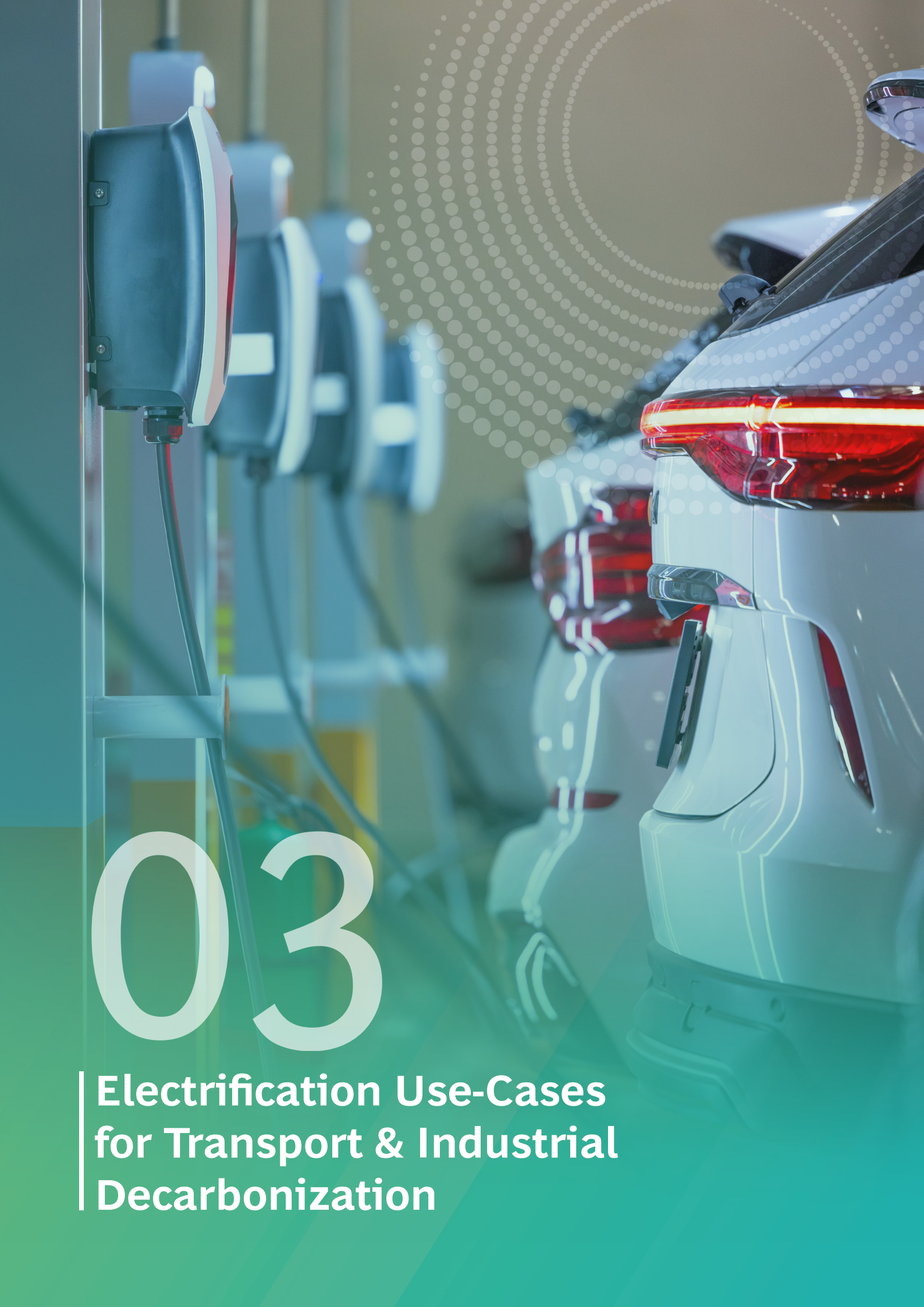
Similarly, India needs to ensure development of a thriving domestic "Green Investment Market" across capital markets as well as financing institutions; 3 key measures can be considered:

- **Domestic capital markets play in green sectors can be enhanced by imposing obligations to invest certain proportion of AUM[11] in green investments,** similar to current obligations for infrastructure sector. For instance, current estimated AUM of LIC, GIC and EPFO stands at ₹68–70 lakh crores as on 31st March 2024—a 5% AUM obligation can unlock ₹3–4 lakh crore from these institutions as well as stimulate further private sector and overseas investment through deepening of bond market. This can be augmented with the requirement to ensure minimum "A" rating for bonds, securing investors from being exposed to undue risk.

- Presence of Banks in RE lending is currently under-indexed—while banks are nearly four times the size of NBFCs in overall credit distribution, in Renewable Energy (RE) financing, banks contribution is limited to ~0.33 times NBFC contribution. **Measures such as expanding the RE quota under Priority Sector Lending (PSL) or obligations for investment in green bonds (Renewable Finance Obligations) can direct bank funding towards green sector.**

- In FY23, Non-Banking Financial Companies (NBFCs) contributed ~33% of the total debt in the Renewable Energy sector, underscoring their critical role in driving green finance. Key players such as IREDA, REC, PFC, and IIFL are instrumental in this space. **To further enhance their impact, removing net-worth-linked investment limits would enable these NBFCs to allocate more capital toward Renewable Energy projects. Additionally, increasing allocations for 54 EC bonds (capital gains bonds which bear low coupon rate) would open new long-term funding channels for Renewable Energy infrastructure.** Given their strategic importance, providing NBFCs with greater flexibility is essential to unlocking more investment in the Renewable Energy sector and accelerating its growth.

11. Assets Under Management



03

Electrification Use-Cases for Transport & Industrial Decarbonization

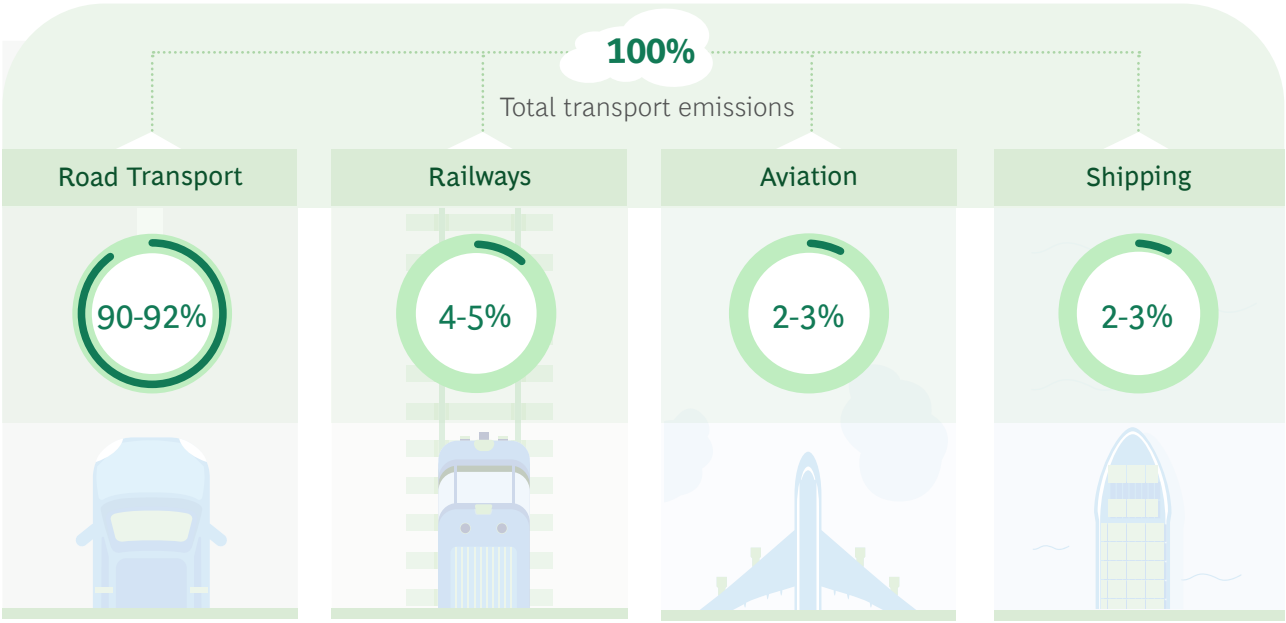
3.1

Decarbonization of Road Transport via E-Mobility

Road Transportation Dominates CO_2 Emissions in India

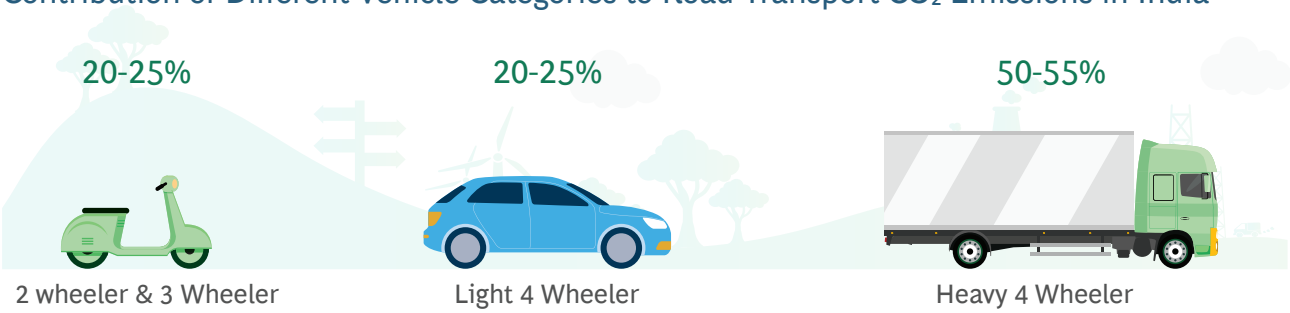
Transportation is a key sector in India's journey towards decarbonization, responsible for ~13% of the country's total CO_2 emissions. In 2022, the sector contributed 324 Mn metric tonnes of CO_2[12]. Road transport, being the dominant source, accounted for over 90% of these emissions. Within road transport, 2-wheelers, 3-wheelers, and light 4-wheelers represent ~50% of emissions, which can be addressed through electrification in the near to mid-term. Therefore, e-mobility can be an important lever in decarbonizing the sector.

Contribution of Different Modes of Transport to CO_2 Emissions in India



Source: CEEW's India Transport Energy Outlook, 2022

Contribution of Different Vehicle Categories to Road Transport CO_2 Emissions in India[1]



1. Calculated using vehicle parc and overlaying CO_2 emissions per kilometer, average distance travelled in a year for different vehicle categories
Source: BCG Analysis

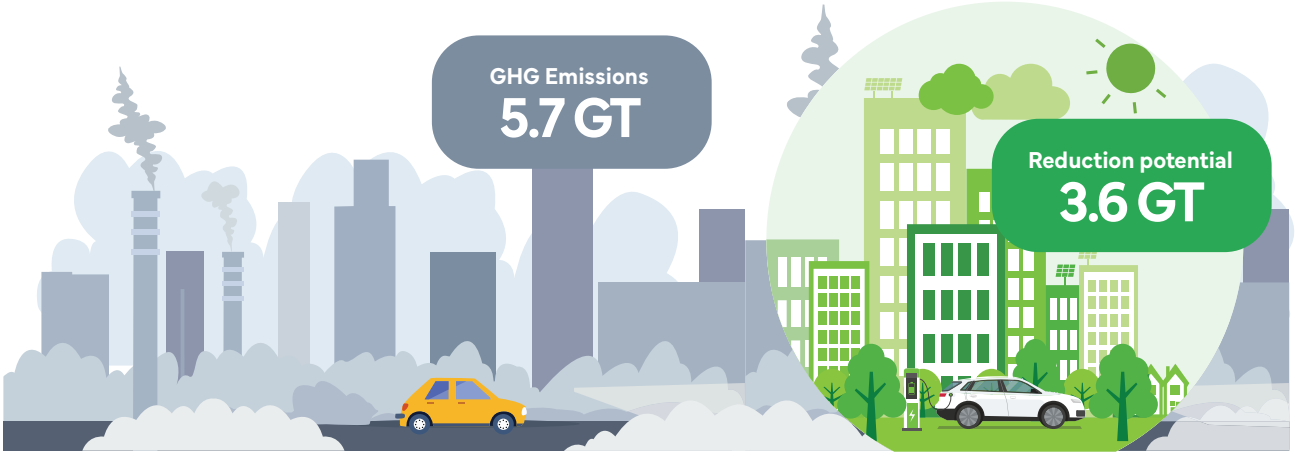
Railways, aviation and shipping comprise 8–11% of transport emissions—potential to decarbonize railways via electrification, aviation via Sustainable Aviation Fuel (SAF) and shipping via bio-fuels and electro-fuels.

12. International Energy Agency (IEA)

EVs can Pave the Way for Decarbonized Road Transport

Two key pathways exist for decarbonizing road transport: fuel cell vehicles and Electric Vehicles (EVs). However, fuel cell technology is still at a nascent stage in India. On the other hand, EVs are already a fast-growing segment and are being deployed at scale across the globe. As the total cost of ownership decreases (driven by falling battery prices) and the charging infrastructure improves, EV adoption is expected to have a strong trajectory.

Decarbonization of Transport Sector will be Driven by a Combination of Multiple Technologies



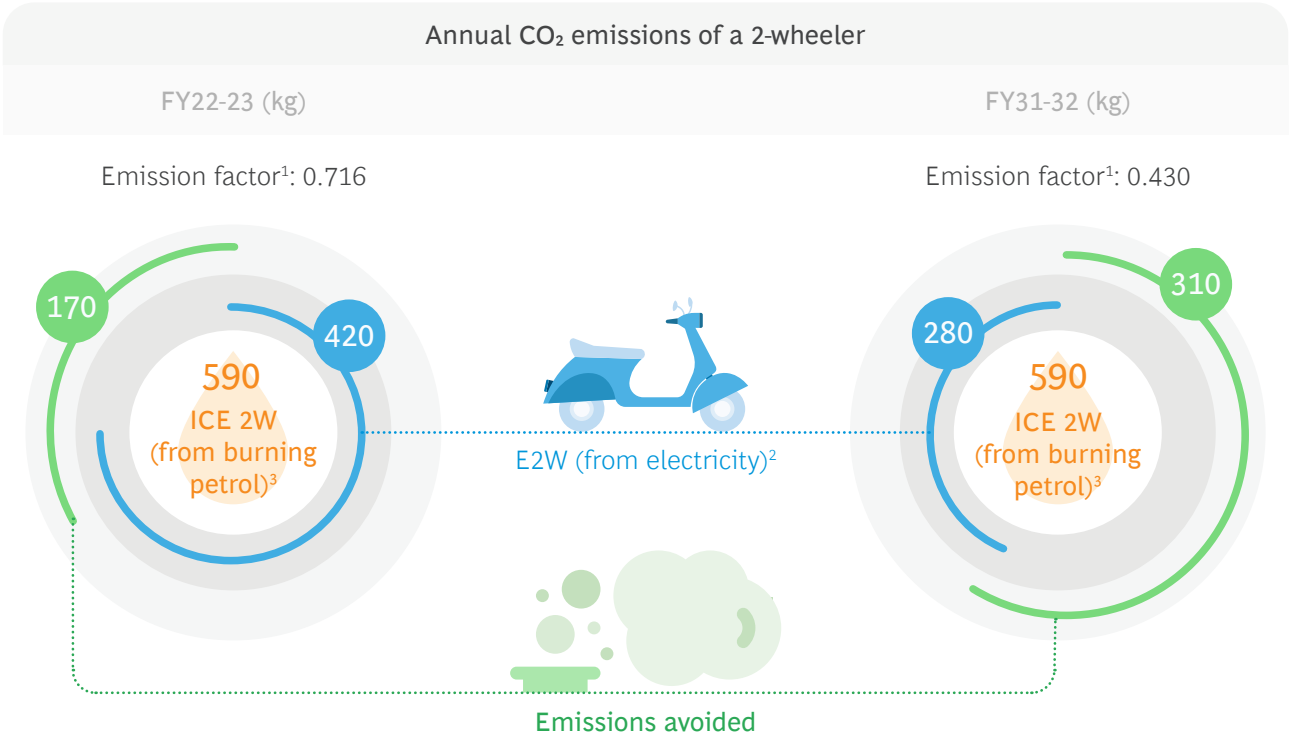
		Subtotals of commercially viables levers considered
Improved ICE	Internal Combustion Engines (ICE) still have potential for optimized efficiency, e.g., using variable compression and mild hybrids. All measures combined have the potential of increasing the efficiency by 30% until 2030	1.2 GT
Electrification	Battery electric vehicles are a fast growing technology. Missing infrastructure for fast charging is no technical hurdle. GHG reduction potential relies on a low carbon electricity generation	2.4 GT[2] → 2.4 GT
Fuel cell	Fuel cells for vehicles are technically available. They lack the required infrastructure for fueling and sufficient capacity for hydrogen production for now. Both factors technically solvable	2.3 GT[1] / 1.8 GT[1]
Fuel Subsitute	Biofuels and Synfuels can be used with minor changes in existing infrastructure. Sustainable production is limited on electricity generation from renewable sources	2.3 GT[1] / 1.8 GT[1] / 0.5 GT / 0.7 GT / 1.2 GT
	Total reduction potential of levers considered	**3.6 GT**

1: Not considered in our scenario given BEVs higher expected market penetration and technological maturity; full potential of fuel cell calculated assuming 100% Renewable Energy mix; **2:** Considering carbon intensity of electricity of 266grCO_2/kWh
Source: UNFCCC; IEA World Energy Outlook 2019; BCG Analysis

Potential to Avoid 50% CO_2 Emissions for each Vehicle Replaced by an EV

India can reduce its transportation-related emissions by replacing Internal Combustion Engine (ICE) vehicles with EVs. Using electricity over fossil fuels, results in 35–40% lower use-phase CO_2 emissions per vehicle even at the current level of RE integration in the grid (emission factor of ~0.72 in FY22–23). As India transitions towards more RE installation by 2030 (emission factor of ~0.43 in FY31–32), this will lead to a ~50% emission reduction per vehicle.

Emission Reduction of a 2W through Electrification (FY22–23 vs FY31–32)

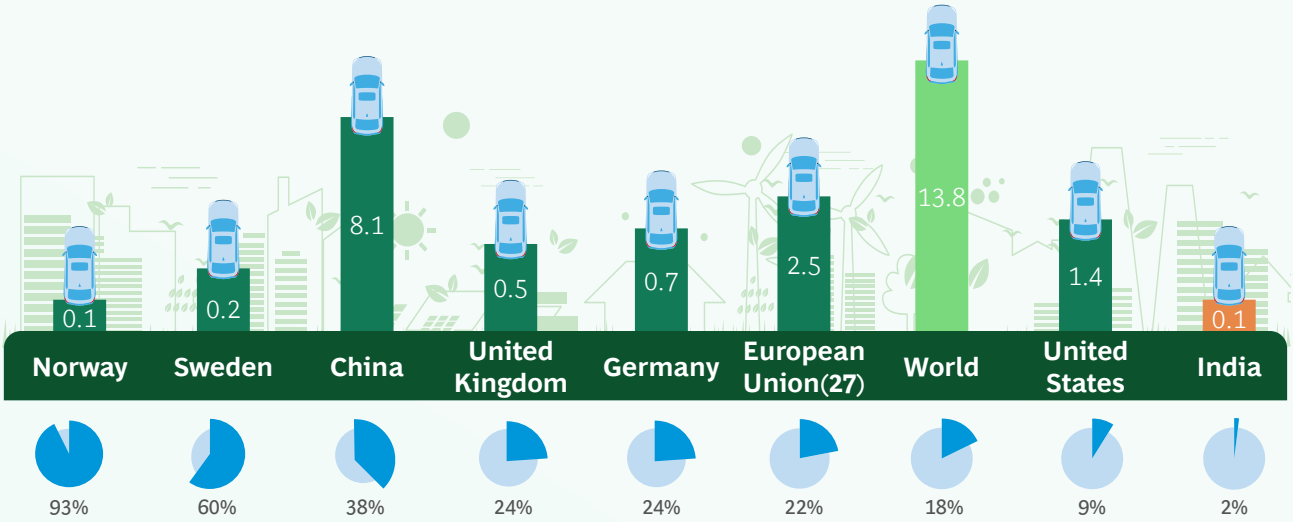


1. As per National Electricity Plan (Volume 1); **2.** Includes losses due to power transmission and distribution, EV charger efficiency; **3.** Calculated using emission factor of 2.3035 kg/L for petrol; emissions involved in petrol production not included
Source: BCG Analysis

Key Policy Recommendations by Leveraging Global Learning

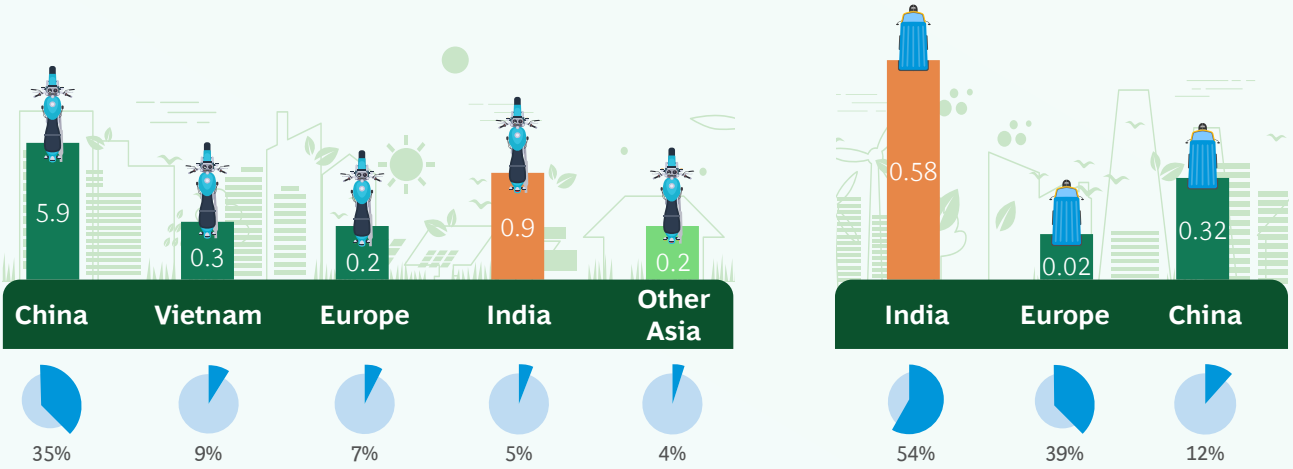
In 2023, penetration of electric cars in India was ~6.4%[13]—significantly lower than the global average of 18%. Norway has emerged as a leader with 93% penetration. For E2W, penetration remains modest at 5% for India, behind Europe (7%), Vietnam (9%), and China (35%). For E3W, India leads in volume and penetration (54%)[14], which can be attributed to their use in public transport, last-mile delivery, and urban commuting.

Electric Car New Registrations and Sales in 2023 (Mn Units)



% share of total car sales

E2W New Registrations and Sales in 2023 (Mn Units)



Source: IEA Global EV Outlook 2024

While EV penetration in India has rapidly increased to ~7.7%[10] in 2024, there is still significant room for growth, especially compared to leading markets. Global EV leaders put in place demand side and supply side enablers to enhance EV adoption—India can benefit from global learning to drive supportive policies for EV.

13. Ministry of Road Transport and Highways. Vahan Dashboard. Retrieved January, 2025;
14. Global EV Outlook 2024, International Energy Agency (IEA)

CASE STUDY

Norway's EV Push Driven by Government, Charge Point Operators (CPOs), and Other Equipment Manufacturers OEMs

Phase 1 (1990–1999): Government Initiatives Fueling Early EV Adoption

- **1990**: CO_2 tax on fossil fuels (~$30/tonne).
- **1996–99:** Exemptions for EVs from road tolls; free municipal parking for EVs.

Phase 2 (2000–2012): Strengthening Public and Private Collaborations

- **2001:** scrapped 25% Value-Added Tax (VAT) on new EV purchases; increased road taxes on non-EVs by 25%.
- **2009–11:** Nissan partnered with local municipalities, including Oslo, to deploy CHAdeMO fast chargers (50kW) across the country, offering free charging for early buyers of the Nissan LEAF.
- **2011:** Norway introduced platforms like NOBIL, a public database for charging station availability, charging speed, and other details.
- **2012:** Combined Charging System (CCS), a standardized EV charging technology that integrates AC and DC fast charging into a single system, was introduced by a consortium of OEMs like BMW, Volkswagen etc. as the de facto standard for EVs.

Phase 3 (2013–2020): OEM-Driven Push for EV Infrastructure

- **2012–13:** Tesla established Supercharger stations (90 kW) across Norway. Free lifetime Supercharging to early buyers of the Tesla Model X and Model Y was offered.
- **2017:** IONITY Joint Venture - BMW, Daimler, Ford, VW & IONITY (charging infrastructure company) partnered with an aim to develop a network of High-Power Charging (HPC) stations across Europe—Leading OEMs partnered with partnered with a charging infrastructure company aiming to develop a network of High-Power Charging (HPC) stations across Europe.
- **Vehicle-to-Grid (V2G):** V2G technology, powered by Nissan, VW and Audi, allowed EVs to send excess power back to the grid, contributing to efficiency and grid stability.

CASE STUDY

EV Adoption in United States Driven by Government Led Initiatives, Public-Private Partnerships and Infrastructure Scale-Up

Phase 1 (1990–2010): Government-Led Initiatives and Early Market Development

- **1990–2000:** The U.S. government introduced policies to incentivize infrastructure and R&D for Alternative Fuel Vehicles (AFVs), including EVs. Notable legislation included the Energy Policy Act of 1992 which provided regulatory support and tax incentives for AFVs.
- **2007:** The Energy Independence & Security Act aimed to reduce dependence on foreign oil and promote renewables, offering loan guarantees for manufacturing EVs, PHEVs, and AFVs along with additional tax incentives for charging infra (50% tax credit).

Phase 2 (2010–2020): Expansion Through Public-Private Partnerships

- **2010–2013:** Major automakers (Nissan, General Motors and BMW) partnered with ChargePoint and other CPOs to install public charging stations. The U.S. Department of Energy funded significant projects like Project EV with Nissan and ECOtality ($115 Mn in funding). During this time multiple crowdsourced apps were also launched.
- **2012:** Tesla launched its Supercharger Network, initially offering free lifetime supercharging for early buyers, significantly boosting EV adoption by reducing range anxiety—starting from 6 stations and expanding to 2k+ stations by 2024.
- **2016–18:** Apps like myAudiConnect and FordPass introduced route planning and remote monitoring. Additionally, Electrify America, born out of VW's Dieselgate settlement, pledged a $2 Bn investment to build a nationwide network of fast chargers, installing ~3500 chargers as of 2023.

Phase 3 (Post 2020): Widespread Adoption and Infrastructure Scale-Up

- **2021:** GM launched Ultium Charge 360 platform with in-app payments integrated with charging networks.
- **2021–22:** Passage of the Infrastructure Investment and Jobs Act committed $7.5 Bn to expand the national EV charging network with a goal to install 500,000 chargers by 2030. More than 60 electric companies have collaborated to install charging stations under the National Electric Highway Coalition.

The Government of India has already proactively implemented various supply side & demand side incentives to promote EVs—Supply side incentives include Production Linked Incentives (PLI) for Automotives & ACC-batteries and EV-policy to attract global manufacturers. Demand side incentives include FAME Scheme for EV customers and PM-Drive for promoting e-mobility for public transportation, culminating in EVs comprising ~7.7%[15] of new vehicle sales.

However, **there is a potential to build further enablers drawing on learnings from global EV leaders, such as:**

- **Use based incentives**
  Norway taxed ICE vehicles (fossil fuel tax & higher road tax) while offering financial exemptions for EVs (toll exemption, free parking, VAT waivers, etc.).

- **Charging infrastructure**
  Charging infrastructure set up in PPP model (led by OEMs) in both Norway and US; with focus on standardized charging.

- **Information transparency**
  Public databases launched in Norway to provide information on charging infra-availability alleviating range-anxiety in customers.

- **Enabling facilities**
  Route planning & remote monitoring apps launched in US offering higher convenience EV users.

Further, In India, EV buyers (especially commercial segment) currently face challenges in financing given differential economics of EV vs. ICE as well as limited insight into resale value.

3 key measures can be considered to ease availability of financing for EVs:

- Inclusion of commercial EV loans under **Priority Sector Lending** enhancing fund flow to the segment.

- **De-couple battery & vehicle (with separate ownership documents) to facilitate leasing/ swapping/pay-per-use models,** thereby enabling flexible financing structures.

- **Establish battery safety standards** & performance certification framework enabling upfront clarity on resale value.

15. Ministry of Road Transport and Highways. Vahan Dashboard. Retrieved January, 2025

From an Electrification Perspective, EVs will only Comprise ~1% of Electricity Demand by FY29–30

As per the current trajectory, it is estimated that EVs will make up 30–35% of new vehicle sales in India in FY29–30[16], driven by factors like favorable economics, improving charging infrastructure, and a push for fleet electrification. In FY29–30, these EVs would create a demand for an estimated 21–23 Bn units (BU) of electricity, which is just ~1% of the projected demand for that year (2.3k BU), while avoiding ~15–17 Mn metrics tonnes of CO_2 emissions (~3–4% of transport emissions) based on the difference between emissions in generating electricity and burning fossil fuels in vehicles. **Therefore, while electricity is a critical input to decarbonize the transport sector, demand from this sector may not be significant from a power market standpoint in the near to mid-term.**

Energy Requirement and Emissions Avoided across EV Adoption Scenarios

Scenario	EVs as percentage of new vehicle sales in FY29-30	Energy requirement in FY29-30 (BU)	CO_2 emissions avoided in FY29-30 (Mn tons)
Moderate adoption	30%[1]	~21	~15
High adoption	35%[1]	~23	~17

1. Promoting Clean Energy Usage Through Accelerated Localization of E-Mobility Value Chain, 2022 (NITI Aayog)
Source: BCG Analysis

16. Promoting Clean Energy Usage Through Accelerated Localization of E-Mobility Value Chain, BCG and NITI Aayog, 2022

3.2

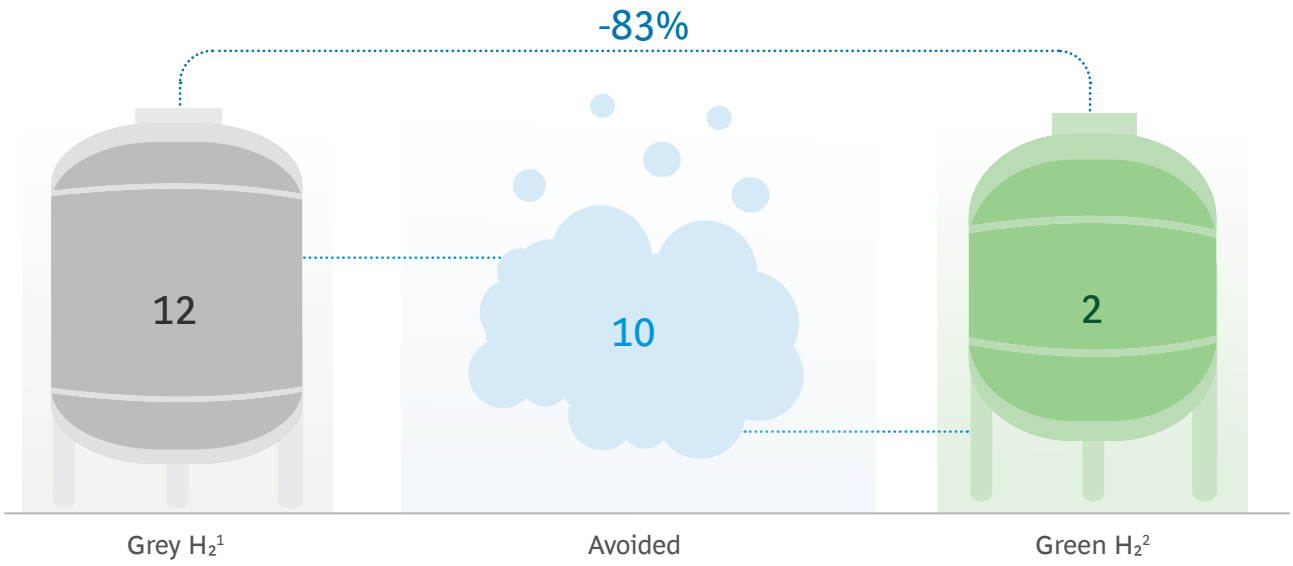
Electrolysis-based Green Hydrogen

Green Hydrogen presents a Significant Opportunity for Decarbonization

Globally, the demand for hydrogen is 95–100 Mn metric tonnes[17] per annum (MMTPA), while India consumes 6–7 MMTPA[18], primarily in refineries and ammonia production. Currently, nearly all hydrogen is grey, mainly produced from natural gas through Steam Methane Reforming (SMR), which is carbon intensive and emits ~12 kilograms[19] of CO_2 into the atmosphere for every kilogram of hydrogen produced.

As countries seek ways to meet climate goals, electrolysis-based Green Hydrogen offers an opportunity to decarbonize industry by using renewable electricity to split water into hydrogen and oxygen. With only 2 kilograms of CO_2[20] emissions allowed for every kilogram of Green Hydrogen produced in India, there is potential to decarbonize hydrogen production by ~83%.

CO_2 Emissions per Kg of Hydrogen Produced (kg)



1. As per Massachusetts Institute of Technology Climate Portal; **2.** As per Ministry of New & Renewable Energy's definition of Green H_2 as having a well-to-gate emission (i.e., including water treatment, electrolysis, gas purification, drying and compression of hydrogen) of not more than 2 kg CO_2 equivalent per kg of H_2
Source: Press Information Bureau, Government of India. (2022). India announces definition of Green Hydrogen

Other than industrial decarbonization, Green Hydrogen is also ideal for long-haul and heavy-duty road transport. As per the International Energy Agency, Trucks and Buses comprise fewer than 8% of vehicles globally (excluding two- and three-wheelers) but contribute to more than 35% of direct CO_2 emissions from road transport. Further, Buses & Trucks contribute to 70–75% of Particulate Matter emissions and Nitrogen Oxide emissions from road transport in India, with trucks comprising 77–80% of this share. Hence, heavy vehicles decarbonization is critical from both carbon emissions and air pollution perspective. Hydrogen vehicles are well-suited for commercial heavy transport applications, offering extended driving ranges and quick refueling times (often just minutes). Moreover, hydrogen's high energy density enables these vehicles to carry larger payloads, overcoming the weight limitations that hinder Battery-Electric Vehicles.

Adoption of Hydrogen Fuel Cell Vehicles (FCVs) is expected to increase as hydrogen and fuel cell costs drop with the experience curve. As per the IEA, FCVs across all road modes across the globe stand at around 93k as of the end of June 2024. Hydrogen use in road transport increased by around 55% in 2023, with heavy-duty vehicles accounting for almost 85% of this growth. Enhancing adoption will also require policy mandates and establishment of requisite fueling infrastructure.

17. MNRE; **18.** Economic Times; **19.** Hydrogen Newsletter, 2023;
20. Press Information Bureau, Government of India. (2022). India announces definition of Green Hydrogen.

Green Hydrogen should be Actively Considered to Replace Grey Hydrogen Demand in India

Producing Grey Hydrogen in India to cater to domestic demand is more expensive than producing it in other countries, since the biggest input cost in the Steam Methane Reforming (SMR) process is natural gas, and India is an importer of Liquefied Natural Gas (LNG). The cost of producing 1 kilogram of Grey Hydrogen from SMR in India can range from $2/kg (based on an administrative price mechanism (APM) price of ~$7.5/MMBTU observed in October 2024) to $3.5/kg (based on a Brent crude oil price of ~$15.2/MMBTU observed in April 2024). This is higher compared to a global average of ~$2/kg.

Thus, for India, Green Hydrogen offers several benefits over Grey Hydrogen:

- **Energy security and import bill reduction:** By transitioning to domestically produced Green Hydrogen, India can reduce its dependence on imported LNG, enhancing its energy security and reducing its import bill.

- **Cost Competitiveness:** Although the current price of Green Hydrogen may appear higher at a single point in time, a 20-year electrolyzer lifecycle analysis reveals that its levelized cost is competitive with Grey Hydrogen. The levelized cost of Green Hydrogen production is estimated to be $2.5–3.5/kg, after factoring in the impact of currency depreciation, which is at similar levels to Grey Hydrogen prices.

Green Hydrogen offtake in India is starting to see movement with several tenders initiated by the Solar Energy Corporation of India (SECI) under the Strategic Interventions for Green Hydrogen Transition (SIGHT) program. These include:

- **SIGHT Program (Mode 1, Tranche II):**
  SECI has issued a Request-for-Selection (RfS) for setting up Green Hydrogen production facilities under this program, with a total capacity of 450,000 metric tonnes per annum.

- **Green Hydrogen Hubs:**
  SECI has called for proposals to establish two Green Hydrogen hubs with a production capacity of 100,000 metric tonnes per annum each, offering central financial assistance of up to ₹100 crore each.

In addition to domestic demand, India is well-positioned to cater to the global market for Green Hydrogen and its derivatives.

Green Hydrogen and its Derivatives are Gathering Momentum with the Launch of Several International Offtake Tenders

Several countries are looking to transition from Grey Hydrogen to Green Hydrogen as a part of decarbonization efforts, and there has been a noticeable shift in the momentum for Green Hydrogen and its derivatives, as evidenced by various international tenders:

- **European Green Ammonia Tender**
  As a part of the H2Global Foundation initiative, a €360 Mn tender was launched to import green ammonia into Belgium, Netherlands, and Germany towards the end of 2022. The tender aims to secure 10-year purchase agreements for green ammonia produced outside the EU, with deliveries expected by 2024–2025. This tender highlights Europe's growing demand for Green Hydrogen-based products, in a bid to lead decarbonization efforts.

- **South Korea's Clean Hydrogen Power Auction**
  South Korea launched the world's first auction for clean hydrogen power generation in May 2024. The tender aims to co-fire ammonia or hydrogen at coal or natural gas plants or use 100% hydrogen in turbines or fuel cells. The government plans to procure up to 6,500 GWh of electricity annually under 15–year contracts starting by 2028. 24 of the 26 companies shortlisted for the auction in August 2024 were based outside the country.

- **TotalEnergies' Green Hydrogen Tender**
  In 2023, TotalEnergies issued a tender to procure 500,000 tons per annum of Green Hydrogen to decarbonize its European refineries. The initiative aims to cut 5 Mn tons of CO_2 emissions annually by replacing conventional hydrogen with Green Hydrogen by 2030. As per the chairman & CEO of TotalEnergies, "By offering to various worldwide suppliers the opportunity to secure medium and long-term contracts with TotalEnergies, we trust we will benefit from the most competitive solutions they have developed."

Further, several countries with limited domestic RE potential have announced targets for Green Hydrogen imports. For example, Japan, South Korea, and Germany are targeting Green Hydrogen imports of 3, 3.9, and 2.7–3.3 MMTPA, respectively[21] in 2030, which represents a sizeable opportunity for exporters.

India is Competitively placed to Become a Global Green Hydrogen Export Hub

The cost of producing Green Hydrogen is on a downward trajectory globally, driven by advancements in electrolyzer technology, falling RE prices, and increased policy support. India is emerging as one of the most favorable geographies for Green Hydrogen production due to its advantage in low-cost RE generation and its expected cost advantage in electrolyzer manufacturing.

India is already making significant strides in the Green Hydrogen export space, with particular emphasis on derivatives like green ammonia—more than 2.5 MMTPA of green ammonia exports are already in the pipeline. This growing export potential underscores the country's efforts to meet international demand while advancing its energy transition goals.

21. Harnessing Green Hydrogen: Opportunities For Deep Decarbonisation In India, NITI Aayog & RMI, 2022

2.5+ Mn Metric Tonnes Per Annum of Green Ammonia Exports in the Pipeline

Company	Project Details	Plant Location	Region of Export	Green Ammonia Demand (Tonnes per annum)
Greenko	GH_2 and GA export to Singapore-Keppel Infrastructure	Tuticorin, Tamil Nadu	Singapore	2,50,000
	Plans to supply GA to Germany's biggest gas trader Uniper	Kakinada, Andhra Pradesh	Germany	2,50,000
	GA supply to Yara	Kakinada	EU	2,50,000
ACME	Supply of GA agreement with IHI Corporation	Gopalpur, Odisha	Japan	4,00,000
Sembcorp	Supply of GA to Sojitz Corporation and Kyushu Electric Power Co Inc of Japan	Thoothukudi, Tamil Nadu	Japan	2,00,000
Ocior	Supply of GA to Swiss trader, Ameropa	Odisha	Europe and Asia	1,00,000
Hygenco	Supply of GA to Swiss trader, Ameropa	Gopalpur, Odisha	Europe and Asia	11,00,000

Source: Press search

Green Hydrogen Production would require a Significant Amount of Electricity from Renewable Sources in 2030

The National Green Hydrogen Mission targets a Green Hydrogen production capacity of at least 5 MMTPA by 2030. In the same year, NITI Aayog envisions a production of 20 MMTPA of green steel and 25 MMTPA of green ammonia for exports to countries like Japan, Korea, and the European Union. Under perfect conditions, 1 kg of electrolysis-based Green Hydrogen production requires ~39kWh of electricity. However, due to inefficiencies, commercially available electrolyzers require ~50kWh for 1 kg, and thus, one MMT of Green Hydrogen requires 50 Bn units of green electricity, i.e., 20–25 GW installed RE capacity. Ensuring a reliable supply of RE RTC power will be critical to maintaining continuous hydrogen production and meeting these ambitious targets. **Achieving the targets in 2030 is expected to place a considerable demand for RE on India's grid from a power market standpoint in the near to mid-term.**

Electricity Required for Green Hydrogen Production

	Commodity	Quantity of commodity (MMTPA)	Quantity of Green Hydrogen required for production (MMTPA)	Electricity required for producing Green Hydrogen (BU)
National Green Hydrogen Mission	Green Hydrogen	5	5	250
NITI Aayog Targets	Green Ammonia	25	4.5	222.5
	Green Steel	20	1	50

Source: National Green Hydrogen Mission; Harnessing Green Hydrogen (NITI Aayog and RMI); BCG Analysis

Key Policy Recommendations to Catalyze Green Hydrogen Ecosystem in India

- In the absence of PPAs, secure offtake is the most pressing challenge towards scaling Green Hydrogen production. While we have seen green shoots in the form of Ammonia tenders, **Government-to-Government (G2G) collaborations will be a crucial strategy to give export impetus to India's Green Hydrogen sector. Structured roadshows—targeted events where governments, investors, and the industry showcase large-scale hydrogen projects—can play a crucial role in consolidating international demand, especially with focus towards net-importer regions such as Japan, Korea, the Middle East and the European Union.** International examples highlight how such partnerships can accelerate market entry, reduce barriers, and secure long-term demand, ultimately helping scale up production and reduce costs. For instance, Germany has established G2G agreements with several countries, including Canada and Australia, focusing on joint research, hydrogen production, and building transatlantic supply chains. Catalyzing the Green Hydrogen ecosystem in India will require securing a critical mass of anchor offtakers (with multiplier effect on ecosystem & infrastructure development) through viability gap funding mechanisms driving hydrogen price competitiveness, assured conformance with international Green Hydrogen standards (e.g., the EU mandates compliance with RFNBO guidelines), and G2G trade agreements (e.g., Germany has agreement with Canada and Australia for join R&D, hydrogen production, & building transatlantic supply chains).

- Electrolyzers constitute 45–50% of Green Hydrogen cost, hence, domestic production of low cost electrolyzers is critical to maintain export competitiveness. As per a CEEW report (2024)[22], India has over 80% indigenization potential for electrolyzers with potential to reduce cost from $350–400/kW to <$200/kW via using alternative materials, optimizing stack specifications, and reducing catalyst loading. Hence, from a policy perspective, the **government should focus on developing a robust manufacturing ecosystem across electrolyzer components with strategic incentives for high-value components (e.g., power systems)**—digital platform can be created bringing to link players across the value chain. Further, there is a need **to promote R&D with well-defined targets** such as minimizing loading of rare metals not available in India and developing advanced membrane technologies to reduce import dependence.

- From a grid balancing perspective, there is a need to **establish harmonized grid connectivity standards for electrolyzers** given high levels of power drawn from grid. Electrolyzers are fairly flexible in terms of ramping and hence can provide grid balancing support as per a CEEW study (2024)[23]—**design of appropriate financial incentives can be explored to leverage electrolyzers to manage solar curtailment as well as grid balancing.**

- **Establish robust Green Hydrogen standards, harmonized with global standards as well as an objective & practical certification framework.** This is especially relevant for India to establish itself as a Global Green Hydrogen export hub.

- Access to large quantum of low cost RE will also be critical for cost competitiveness (50–55% of Green Hydrogen cost)—5 MMTPA 2030 target will require 100–125 GW RE capacity. Ensuring availability of adequate land and transmission infrastructure will be critical for quick RE scale-up. In this regard, **proactive planning for transmission infrastructure can be initiated at identified Green Hydrogen Hubs.**

- **Promotion of Hydrogen Fuel Cell Vehicles in India** will require policy support across multiple levers, including, R&D for cost-effective indigenized manufacturing of fuel cells and refueling stations as well incentives to establish local manufacturing ecosystem. Further, establishing robust network of hydrogen fueling stations will be critical for the uptake of FCVs—currently ~40x more expensive than electric charging stations[24]. There are already some policy green shoots with the MNRE issuing guidelines for the implementation of pilot projects for Hydrogen FCV usage and fueling station development in 2024—with a budgetary allocation of ₹496 crore till FY26. **Given high upfront investment in R&D and infrastructure development, it will be critical to establish clear targets for scaling adoption to drive efficiencies.** For instance, Japan has set a clear target of deploying 800,000 FCVs by 2030, providing subsidies for purchase along side nation-wide network of 1,000 fueling stations.

22. Council on Energy, Environment, and Water (CEEW). (2024, September). *How can India indigenise hydrogen electrolyser manufacturing?*;
23. Council on Energy, Environment, and Water (CEEW). (2024, September). *The impact of Green Hydrogen on India's energy transition*;
24. World Economic Forum. (2024, December). *How hydrogen-powered vehicles will help India reach its emissions targets.*

3.3

Electrification of Industrial Processes

The industrial sector is a significant contributor to global CO_2 emissions, accounting for ~25% of emissions worldwide, and is also a big electricity consumer by end user. In India, the industrial sector accounts for nearly 40% of the total electricity consumption with 6 key industries predominantly driving electricity demand—Iron & Steel, Aluminium, Mineral Oil & Petroleum, Cement, Chemical and Textiles in descending order of consumption[25].

Electricity Consumption Across Industries

Name of Industry	Iron & steel	Aluminum	Mineral Oil & Petroleum	Cement	Chemical	Textile	Others	Total
Energy Consumption share (in%)	25.4%	19.9%	9.8%	8.5%	6.9%	5.5%	24.0%	100.00%

Note: BCG Analysis based on the consumption data of captive power plants in Industries having demand > 0.5MW for 2021-22 as per CEA General Review 2023

India has already seen rapid increase in C&I greening due to supportive policies, innovative structures and declining RE costs. Over the past two years, the C&I market has grown significantly in size with a total of ~30 GW installed capacity as of December 2024[26].

Several states, including Karnataka, Maharashtra, Gujarat, and Tamil Nadu, have implemented supportive RE open-access policies with banking support, transmission waivers, etc., which has driven growth for the RE sector. Further, innovative models such as virtual PPAs have been leveraged for flexible procurement of commercial and industrial consumers.

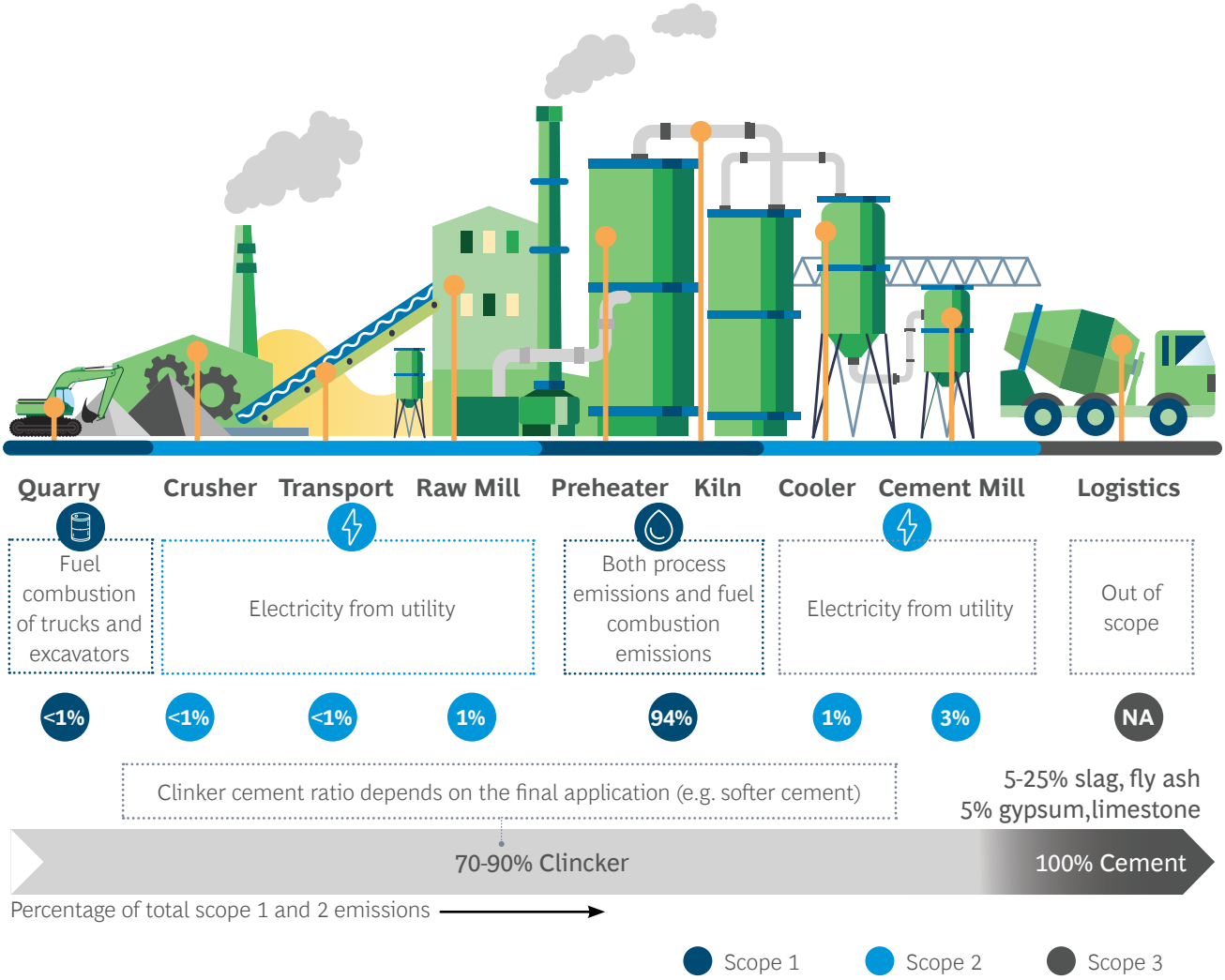
Globally, Iron & Steel and Cement are amongst the Most Energy Intensive Sectors and Carbon Intensive Industries—Making it Essential to Modernize Infrastructure and Processes to Decarbonize these Industries.

In India, Iron & Steel production is responsible for around 12% of the country's total emissions[27], reflecting its heavy reliance on carbon-intensive processes. Globally, around 70% of steel is produced using the traditional Blast Furnace-Basic Oxygen Furnace (BF-BOF) method, which emits between 2,300–2,400 kilograms of CO_2 per tonne of crude steel due to its dependence on coal and fossil fuels[28].

In 2018–19—the cumulative CO_2 emissions from manufacturing 337 Mn tonnes of cement were estimated at 218 Mn, i.e., 0.66 tonnes of CO_2 per tonne of cement produced[29]. As per estimates, 56% of the emissions is due to calcination of limestone in the kilns, whereas the remaining 32% and 12% is due to combustion of fuels for process-heating applications and electricity used during manufacturing respectively[30]. Overall, ~94% of the total emissions are associated with the production of clinker. In India, coal and pet coke are primarily used in kilns as fuel in clinker making along with the use of power from non-clean sources—driving the carbon emissions.

25. CEA, General Review 2023 as reference; **26.** India RE Navigator. (2024). Utility-scale solar and wind data; **27.** Steel Decarbonisation in India, IEEFA & JMK Research, 2023; **28.** Greener Steel, Greener Mining, BCG, 2022; **29.** CEEW, Evaluating Net-Zero for the Indian Cement Industry;
30. BCG Analysis, CEEW,Evaluating Net-Zero for the Indian Cement Industry.

Cement Production Process and Emission Sources Across the Value Chain



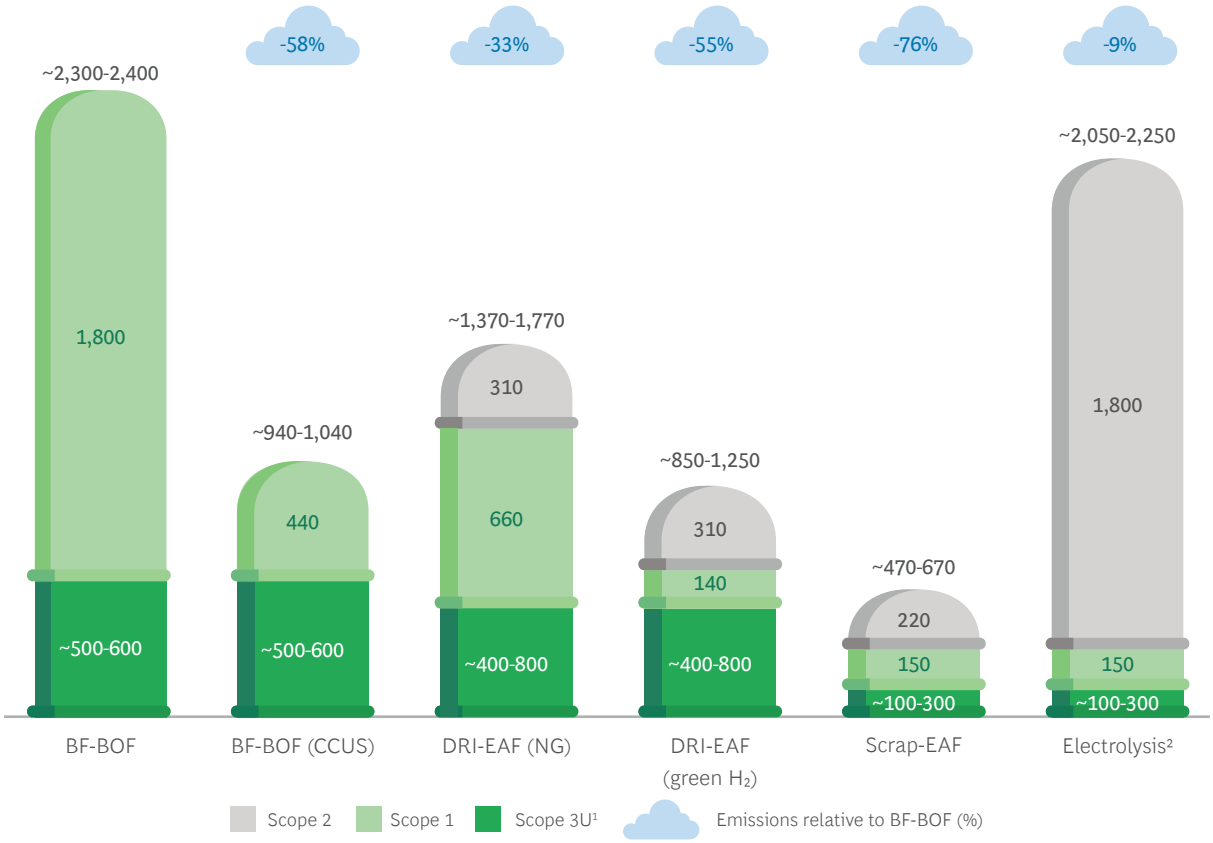
Source: BCG Analysis

Electrification Pathways for Decarbonization of Iron & Steel and Cement Sectors

One promising solution to address the substantial carbon emissions from the Iron & Steel and Cement industries is using electricity to decarbonize the production processes. For example, one of the most effective technologies in this shift is the Electric Arc Furnace (EAF), which relies on electricity to produce steel rather than coal-based processes, significantly reducing emissions. Looking to the future, integrating Green Hydrogen into the steelmaking process is seen as another potential game-changer. In the Direct Reduced Iron-EAF (DRI-EAF) method, hydrogen is used to reduce iron ore instead of coal. This can lower emissions to 850–1,250 kg CO_2 per tonne of steel, representing a 55% reduction compared to traditional methods. This combination of electrification and Green Hydrogen presents a promising route for creating a sustainable steel industry.

Comparison of CO_2 Emissions Across Steel Production Pathways

Scope 1, Scope 2, Scope 3U[1] Emissions (kg CO_2/t crude steel)



1. Scope 3U = Scope 3 upstream emissions; **2.** Molten oxide electrolysis.

Note: Scope 2 emission estimates are based on electricity grid emission factor of 430 kg CO_2/MWh; this falls to zero with 100% green electricity. BF-BOF Scope 2 emissions are negligible, as self-sufficiency in meeting electricity needs is assumed. BF = Blast Furnace; BOF = Basic Oxygen Furnace, CCUS = Carbon Capture, Utilization, And Storage; DRI = Direct Reduced Iron; EAF = Electric Arc Furnace; NG = Natural Gas.

Source: BCG Analysis

Additionally, for Iron & Steel processing, electrolysis-based methods like Low Temperature Electrolysis (LTE) and Molten Oxide Electrolysis (MOE) are being developed to reduce emissions significantly.

Whereas to address the carbon emissions from cement production, it becomes essential to focus on replacement of power with renewable sources of energy and increased adoption of Waste Heat Recovery system to capture and use heat released during the process for power generation. This will unlock significant emission reduction to the 44% currently attributed to electrical and thermal. Additionally, global pilots for alternate production technologies are underway with companies like SaltX and Sublime Technologies working on replacing traditional rotary kiln with advanced innovations like the use of plasma arc furnace technology to produce clinker and deploying electrolyzers to convert limestone & other inputs into Ordinary Portland Cement (OPC).

While still in their pilot phases, several emerging technologies hold significant potential to decarbonize Iron & Steel and Cement production in the future, highlighting the growing importance of electricity in industrial processes.

Electrification Pathways are Not Yet "In the Money"

While emerging decarbonization technologies, as elucidated above, show great promise, they are still in the pilot phase and not yet commercially viable. Scaling them up will require significant capital investment and access to large quantities of low-cost electricity to drive the large-scale energy transition.

The H_2 DRI-EAF technology, which has the potential to significantly reduce emissions, is a breakthrough in Iron & Steel production. Global leaders like ArcelorMittal have expressed strong interest in adopting this technology. In India, NITI Aayog has projected the use of 20 MMTPA of Green Hydrogen to produce green steel. However, the high costs associated with its implementation remain a substantial barrier to widespread usage.

Existing steel plants are often decades old and would require significant retrofitting or complete overhauls to adopt these newer methods, leading to high replacement costs. For instance, retrofitting an existing 2 Mtpa steel plant to adopt H_2 DRI-EAF technology would cost $1.0 to $1.5 Bn for brownfield conversions, while new greenfield projects could range from $1.3 to $2.0 Bn. Even after the upfront investment, the per-unit production cost of low-carbon steel remains higher than that of conventional methods. We estimate that the per-unit production cost of H_2 DRI-EAF is 109% higher than steel produced using the traditional BF-BOF method. This makes it difficult for industries with tight margins and global competition to justify the switch.

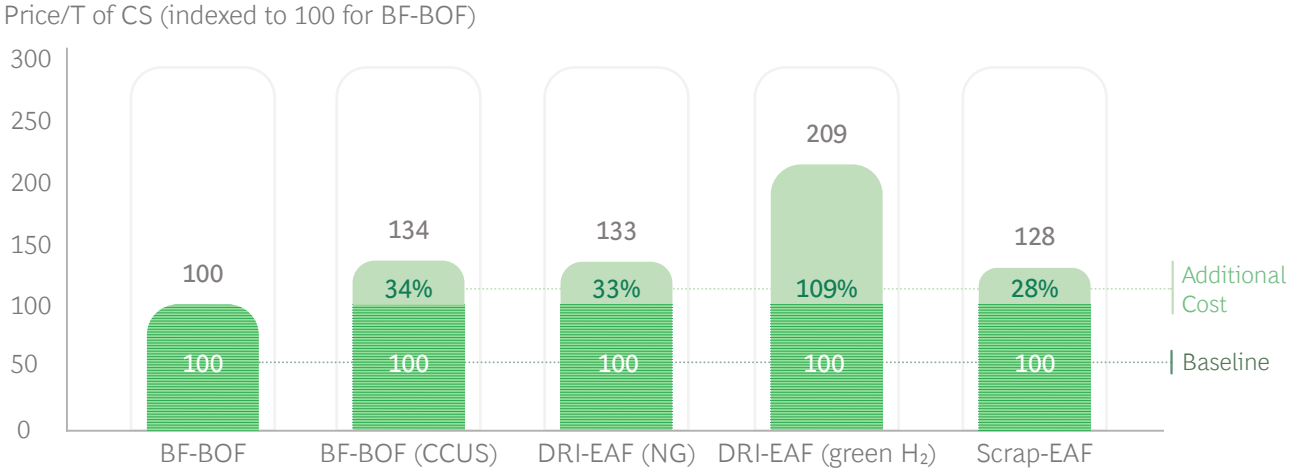
Similarly, the ongoing pilots for alternate cement production processes are highly energy intensive and are not yet commercially viable for higher production volumes. This cost disparity is a significant hurdle in achieving widespread adoption of these cleaner technologies.

Replacement Costs Associated with H_2-DRI-EAF Conversions

	Brownfield total conversion	Brownfield NG to H_2-DRI-EAF	Greenfield H_2-DRI-EAF
Existing Tech	BF-BOF	NG-DRI-EAF	N/A
Target Tech	H_2-DRI-EAF	H_2-DRI-EAF	H_2-DRI-EAF
DRI Feedstock	100% green H_2	100% green H_2	100% green H_2
Estimated CapEx	$1.0-1.5 Bn	<$50 M[1]	$1.3-2.0 Bn

1. Excludes cost of electrolyzer, assuming H_2 sourced via supply contract. Upgrades needed include third stage compressors for H_2 and additional heating and cooling controls
Note: All CAPEX ranges provided for 2.0 Mtpa CS steel plant
Source: Unlocking the first wave of breakthrough steel investments, Energy Transmission Commissions, 2023

2030 Forecast: Price Comparisons of Steel Technologies vs. BF-BOF



1. 75% capture rate, 85 €/t CO_2 capture cost, 30 €/t CO_2 transport and storage cost; **2.** Green H_2 cost 6.5 €/kg
Note: ETS CO_2 costs not included **Source:** BCG Analysis

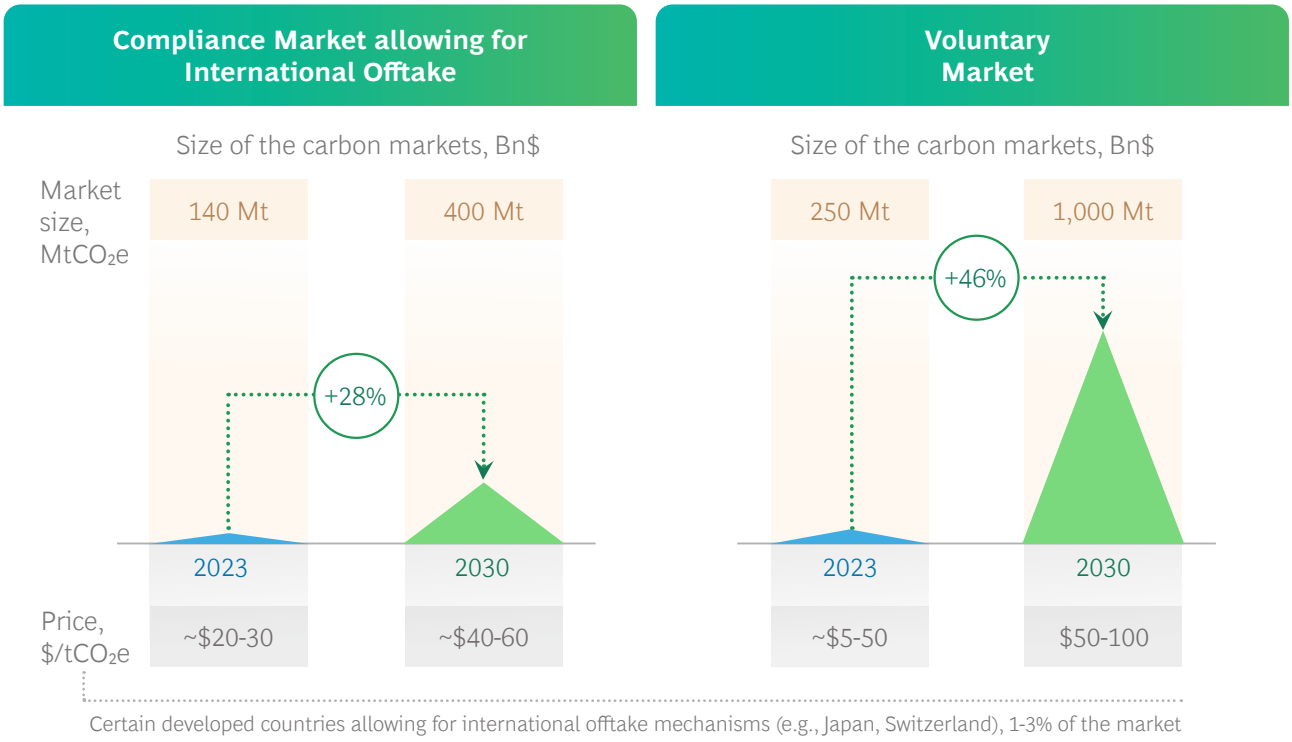
Carbon Markets & Trading can be a Crucial Lever to Support Industrial Decarbonization

Decarbonizing industries like Iron & Steel and Cement, some of the largest emitters of CO_2, is particularly challenging due to the high cost of low-carbon technologies. Given the scale of their emissions, it is crucial to implement carbon pricing mechanisms, such as carbon markets and taxes, to incentivize industries to reduce their carbon footprint. By attaching a cost to emissions, these markets create financial pressures for companies to invest in cleaner technologies and shift toward more sustainable production methods.

The global carbon market is projected to grow substantially by 2030, with the compliance market expected to expand by 28% and the voluntary market by 46%. This expansion will incentivize industries to reduce emissions, innovate, and adopt cleaner technologies.

Carbon Offtake

There are two main types of target markets that can be potentially leveraged to compensate costs associated with decarbonization



Source: Voluntary Carbon Market Insights; CORSIA; IHS Markit; IEA World Energy Outlook; Reuters; Expert interviews; BCG Analysis

Carbon pricing can take various forms tailored to regional regulatory frameworks and economic goals. In India, the Perform, Achieve, and Trade (PAT) Scheme is already in place, facilitating the trading of Energy Savings Certificates (ESCerts) to promote energy efficiency in industries. Since 2015, this scheme has led to a reduction of over 106 Mn tonnes of CO_2[31]. India is also set to launch its Carbon Credit Trading Scheme (CCTS) by 2026, including compliance-based and voluntary markets, marking a significant step toward reducing industrial emissions and aligning with global sustainability goals.

On a global scale, the European Union's Emissions Trading System (EU ETS) is the largest carbon market. It operates on a Cap-and-Trade model that significantly reduces emissions in the power and industrial sectors. The EU has recently extended this system by introducing the Carbon Border Adjustment Mechanism (CBAM). CBAM imposes a carbon cost on high-emission imports such as steel, cement, aluminum, and fertilizers, ensuring that imported products meet the EU's stringent environmental standards.

31. Bureau of Energy Efficiency, Ministry of Power

Impact of CBAM on Indian Exports

CBAM is poised to substantially impact India's emissions-intensive industries, particularly steel and cement, which rely heavily on exports to the EU. Currently, 26% of India's steel exports, valued at $5.4 Bn, and 6.1% of its cement exports, valued at $5.7 Mn, are destined for the EU[32]. These sectors may face rising costs and competitive pressures due to CBAM's implementation. The estimated carbon penalty for India's steel exports is expected to be between €170–180 per tonne of crude steel, based on an assumed carbon price of €100 per tonne under the EU ETS. With India's steel industry emitting ~2.55 tonnes of CO_2 per tonne of steel, this penalty reflects the gap between current emissions levels and the allowances set under CBAM, placing additional financial pressure on Indian steel producers.

Expanding carbon markets and enforcing carbon pricing mechanisms can make the energy transition more economically viable for high-emission industries like steel and cement. These markets drive innovation and investment in cleaner technologies and help align industries with global climate goals. As penalties for carbon emissions increase, industries will be further motivated to decarbonize, ensuring long-term sustainability and reducing the global carbon footprint.

Electrification of Industrial Processes would require a Significant Amount of Electricity

Electrifying industrial processes would necessitate a significant increase in electricity demand as fossil fuel use is replaced. This presents a considerable opportunity for RE developers to align with India's Renewable Energy ambitions and meet the growing electricity needs.

For instance, the DRI-H_2-EAF process, powered by Green Hydrogen, requires substantial energy input.

India's 2030 Target: 300 Mn Tonne of Steel Production

Steel Production Via DRI-EAF-H_2	Target Production (Tonnes)	Step 1: DRI via H_2 (TwH/Tonne)	Step 2: EAF (TwH/Tonne)	Total Electrcity Requirement[1] (In TwH/Tonne)
5%	15,000,000	41.25	6.6	47.85
10%	30,000,000	82.5	13.2	95.7
20%	60,000,000	165	26.4	191.4
30%	90,000,000	247.5	39.6	287.1
40%	120,000,000	330	52.8	382.8

1. Total Electrcity Requirement here refers primarily to the energy consumed in the two most significant steps- as mentioned above
Source: Reports from European Parliament & Institute for Materials Processes,BCG Analysis

As India aims to produce 300 Mn tonnes of steel by 2030, the shift to cleaner, low-emission technologies will play a critical role in decarbonizing the sector. However, as the table above illustrates, these technologies are highly energy intensive. Transitioning to these methods on a large scale will require substantially increasing RE capacity.

32. Global Trade Research Institute

Key Policy Recommendation to Expedite Industrial Decarbonization

- **Establish clear standards and certification framework**, in line with global standards (e.g., CBAM in EU), for what constitutes Green, e.g., Ministry of Steel has recently released a Taxonomy for Green Steel with defined emissions intensity across different sustainability grades. Also, there will be a need to create training program for independent auditors, who can offer these emissions validation & certifications.

- **Promote R&D leveraging international collaboration** to achieve financial feasibility for Carbon Capture, Utilization and Storage (CCUS) technologies to drive emissions reduction in hard to abate sectors, for example, Cement, BF-BOF Steel, etc.

- **Offset CCUS costs** by establishing domestic mandates for utilization of captured carbon in downstream applications (e.g., industries such as rubber & tyres, plastics, enhanced oil recovery, etc.) as well as carbon trading creating additional revenue streams.

- **Create critical anchor set of off-takers via G2G collaborations as well as mandate for certain share to be used for domestic government infrastructure projects.** This will provide the impetus for ecosystem development as well as drive economic viability for initial infrastructure investments.

Further, **Greening of industries will require significant quantum of Green Hydrogen & access to green power,** and hence is critically dependent on enabling these sectors. Supportive policies across green power procurement such as open access waivers and banking availability will also have implications for industrial decarbonization.



04

Unlocking Enabling Environment for a Green Power Transition

Creation of Green Skill Talent Pool

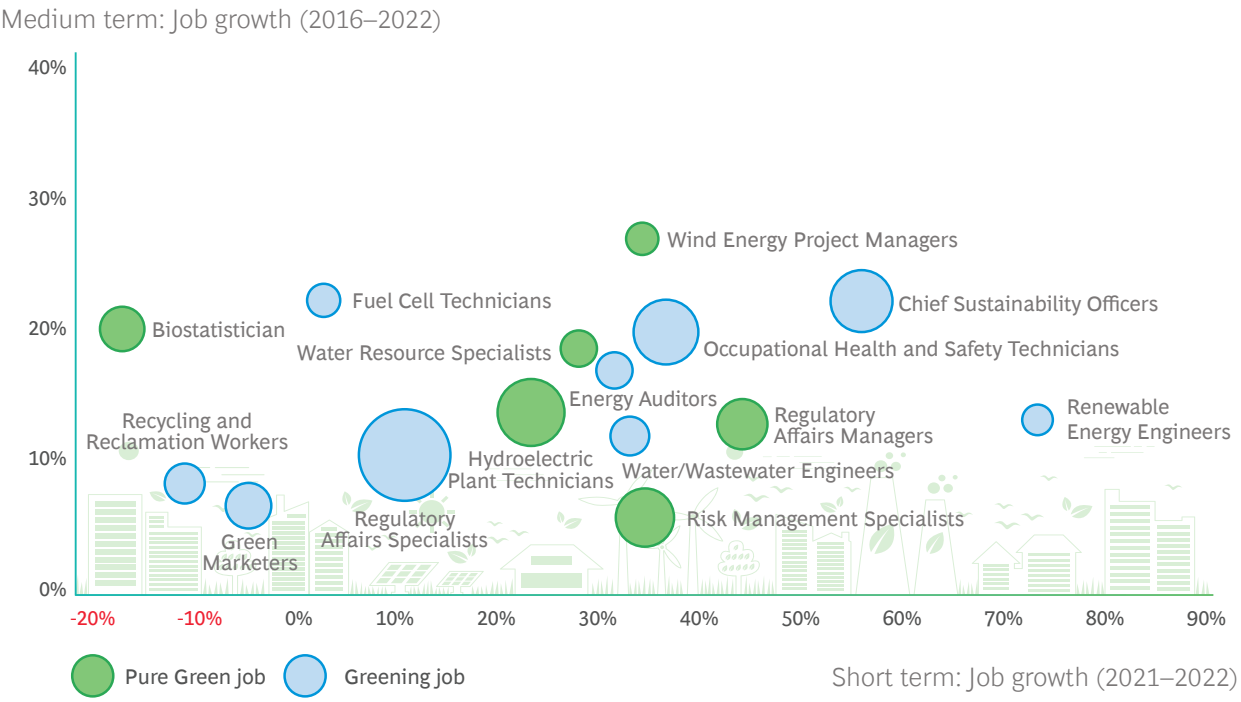
Green Jobs are Growing at a Fast Rate, with Varying Intensity and Types of Green Skills Required

The International Labour Organization (ILO) defines green jobs as decent jobs that help protect or restore the environment. These jobs can be in traditional industries like manufacturing and construction or new green sectors like Renewable Energy. Green jobs impact the talent landscape on two levels—creating new job profiles (e.g., hydrogen engineer) and requiring green skills within existing job profiles; the latter could potentially impact up to 100% of all employees.

The intensity of green skills needed for these jobs varies. Some "greening" jobs, like compliance managers, require several green skills, but not exclusively. Other "pure green" jobs, like material scientists, are entirely based on green skills. A look at fast-growing jobs shows that both types are growing at a high rate, making them essential in the future:

Most Jobs Requiring Green Skills are Not Traditional Green Jobs

Fastest-growing pure green and greening jobs globally



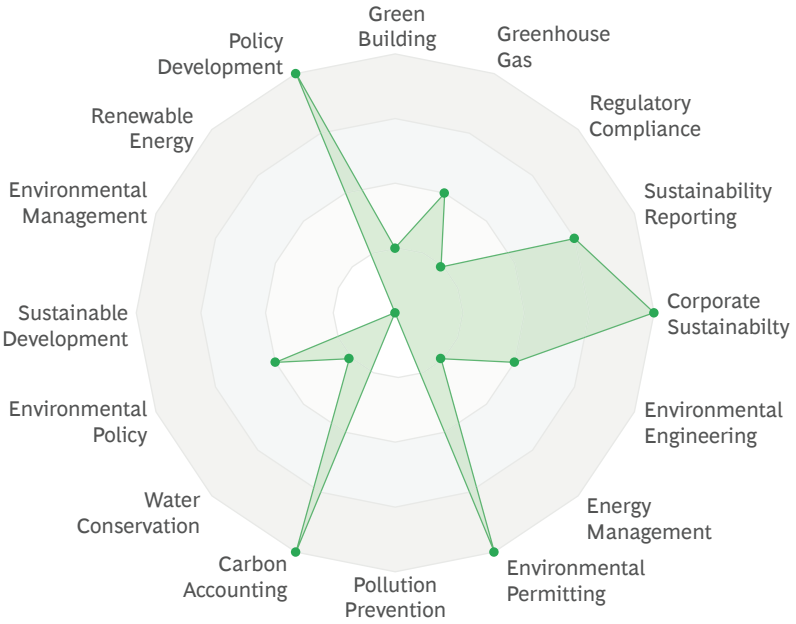
Note: Bubble size indicates share of Titles in the sample where the job was among the fastest-growing in 2016–2022;
Source: LightCast; BCG Analysis

The demand for specific green skills required also varies depending on the job. For example, skills like pollution prevention and reducing greenhouse gas emissions are growing much faster for Chief Sustainability Officers than RE Engineers. However, some skills, like carbon accounting, are growing rapidly for both roles, with more than 70% annual growth. Interestingly, skills not usually linked to engineering, like policy development and corporate sustainability, also see high growth for RE engineers. This suggests that future green jobs require people to learn new skills across different areas.

Growth Rate of Specific Green Skill Demand Varies by Job Profile

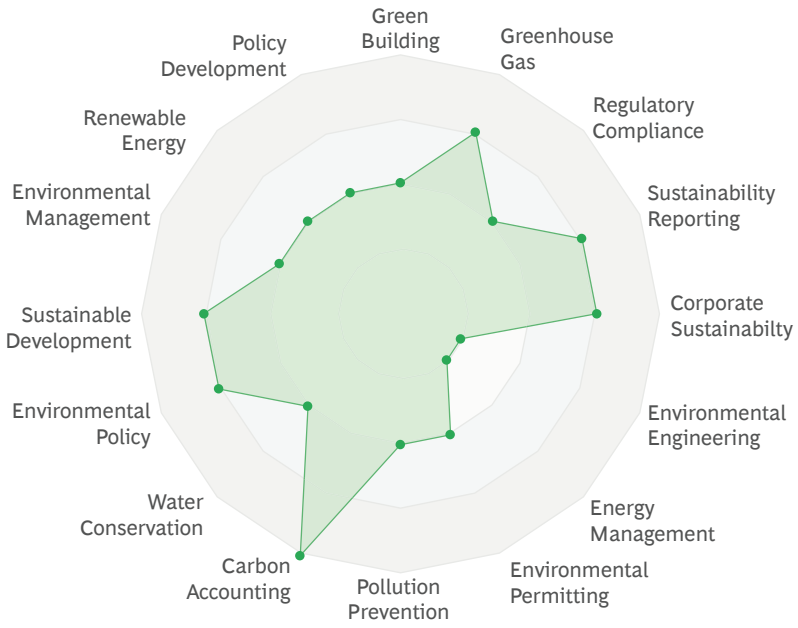
Renewable Energy Engineer: Engineering and Technology

Skill demand growth (2018–2022)
Low (0) to High (4) assessed by CAGR



Chief Sustainability Officer: Sustainability Strategy

Skill demand growth (2018–2022)
Low (0) to High (4) assessed by CAGR

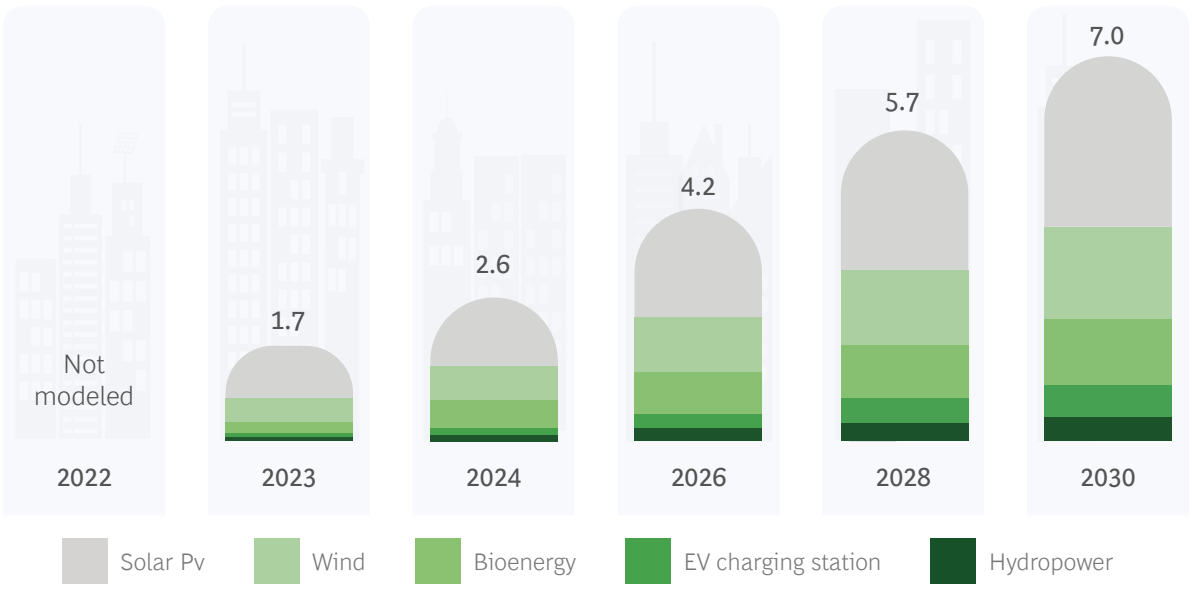


Note: Spider web values oriented on CAGR—CAGR for skill demand (2018-2022) calculated and ranges divided into buckets, which are reflected on the spider web (0 = negative CAGR; 1 = <20%; 4 = >70%)
Source: BCG Analysis

The World could Face a Shortage of 7 Mn Green Energy Workers by 2030

Within the green energy sector, a global shortage of 7 Mn workers is estimated by 2030[33]. This gap is expected to be the highest in solar and wind energy. In addition to unskilled or semi-skilled workers (e.g., solar panel installers, turbine maintenance workers, etc.), high-skilled workers will be needed (e.g., rooftop solar grid engineer, condition monitoring system engineer for wind power plants, etc.). LinkedIn's Global Green Skills Report highlights that the share of jobs requiring at least one green skill grew at an annualized rate of 9.2% between 2018 and 2023, while the share of green talent grew by only 5.4% in the same period, which also points towards a global green workforce shortage.

Number of Jobs where Demand is Greater than Supply (In Mn)



Note: Capacity for each category taken as APS (announced pledges scenario).
Source: BCG Climate Migration Model; IRENA; IEA; IPCC; World Energy Outlook 2023.

Green Energy and Green Hydrogen are Expected to Create ~3 Mn Jobs in India by 2030

As of December 2024, India has about 209.5 GW of Renewable Energy capacity. The CEA projects that an additional 284 GW will be installed by 2030. Most of this will come from solar energy (202 GW), followed by wind (53 GW), hydropower (26 GW), and bioenergy (3 GW). This new capacity (excluding rooftop solar) is expected to generate around 0.5–0.6 Mn jobs. The PM Surya Ghar scheme is also expected to create about 1.7 Mn jobs in the rooftop solar sector, while the National Green Hydrogen Mission aims to create 0.6 Mn jobs. Together, green energy and hydrogen will generate approximately 2.8–2.9 Mn jobs in India by 2030[34].

With around 4.5–5 Mn people entering the workforce each year, India is expected to have enough workers to meet the growing demand for green jobs. However, training them in the right green skills will be crucial. The Skill Council for Green Jobs (SCGJ) offers over 50 courses covering solar, wind, small hydro, biomass, and Green Hydrogen. A large workforce gives India a unique advantage in a smoother transition to green energy compared to other countries, as long as necessary skills are imparted. India could even export skilled workers to aid the global energy transition. The following table illustrates some of the technical and non-technical skills currently available through the Skill Council for Green Jobs:

33. Mind the Green Gap: Will a 7M+ Green Energy Worker Shortage put the 1.5° target at risk?, BCG, 2023; **34.** Press Release

Illustrative List of Qualifications Listed in the SCGJ Green Jobs Handbook

RE Category	Technical qualifications (low skill)	Technical qualifications (high skill)	Non-technical qualifications (low skill)	Non-technical qualifications (high skill)
 Solar Energy	**Solar Domestic Product Assembler** - Assembles fabricated parts of small DC light sub assembly units - Tests and calibrates the assembled units - Repairs refits and handles warranty claims	**Rooftop Solar Grid Junior Engineer** - Checks, inspects, interconnects and tests different components of the grid connected solar rooftop PV power plant - Ensures compliance with all relevant codes, standards and safety requirements		**Solar Photovoltaic Entrepreneur** - Ventures into solar market to lead an enterprise - Applies knowledge of solar business models, market, technical knowledge of solar PV plants/ system, along with components procurement and financing
 Wind Energy		**Condition Monitoring System (CMS) Engineer —Wind Power Plant** - Installs and commissions CMS of wind power plant - Monitors the operation and maintenance of the CMS with a continuous stream of system data	**Project Assistant Planner—Wind Power Plant** - Plans workflow for turbines & electrical systems, erection & commissioning (E&C) - Conducts statistical studies of product quality and time usage - Analyzes production costs while complying with all operational manuals, applicable codes, standards and safety requirements	
 Bioenergy	**Biomass Pellet Manufacturing Junior Technician** - Handles production, storage, and management of biomass pellets - Looks after biomass receiving, pre-processing/ densification and storage to maintain quality and safety as per standards.	**Plant Head-Operations (Compressed Biogas/ Waste To Energy)** - Develops and implements organizational strategies and policies to monitor operation and maintenance of the production unit - Ensures resource optimization, waste management and documentation, manages HR in the CBG Plant and other administrative activities	**Bio-Energy Micro Entrepreneur** - Set up a production unit for manufacturing biomass pellets from agriculture waste or setting up small biogas unit at site - Develops a business plan, hiring the human resources, acquiring financial and material resources, providing leadership, and drives the company's strategy	**Manager-Waste Management** - Carries out market analysis and formulates the business plan for the center. - Ensures compliance of applicable statutory laws, policies and procedures relating to the center. - Specializes in overall operations of biomass depot, compost yard, dry waste collection sector and associated businesses

RE Category	Technical qualifications (low skill)	Technical qualifications (high skill)	Non-technical qualifications (low skill)	Non-technical qualifications (high skill)
Small Hydropower	**Small Hydro Power Plant Technician** - Operates, tests and maintains different electrical, hydro-mechanical, civil components of small hydro power plant - Meets performance and reliability needs by incorporating quality workmanship and complying with all applicable codes, standards and safety requirements			
Green Hydrogen	**Green Hydrogen Plant Junior Technician–Electrolyzer** - Installs electrolyzer units along with other equipment of a Green Hydrogen plant, along with associated civil works - Performs pre-commissioning checks/tests and install & commissions electrolyzer units along with other sub systems	**Electrolyzer Manufacturing Plant Supervisor** - Oversees various aspects of the electrloyzer manufacturing process to ensure efficiency, safety, and quality - Maintaining the manufacturing process and meet production goals while adhering to safety and environmental standards		**Green Hydrogen Plant Entrepreneur** - Identifies the potential market and the client needs/ requirements to propose the right kind of technically and economically feasible solution to set up Green Hydrogen plant - Undertakes specific works/ sub component installations of a Green Hydrogen plant

Source: SCGJ Green Jobs Handbook

Key Policy Recommendations to Capitalize on the Green Skills Gap

- **Establish Green Skilling "Centers of Excellence"** providing comprehensive courses in line with skill requirement for each "green" job family, in line with global standards & leveraging global partnerships. These centers should offer programs for young graduates as well as provide upskilling for experienced engineers and re-skilling programs for workers in carbon-intensive industries. An example of a successful re-skilling program is the $17 Mn fund set up in the UK to re-train 4,000 oil & gas workers.

- **Position India as a "global green talent hub" via partnerships with countries seeking green talent.** For instance, an integrated training, visa and migration strategy can be created in partnerships with countries facing green skills gap (e.g., Australia) which can be mutually beneficial—these countries can serve as investors in India's vocational training programs and offer visa access drawing on India's skilled talent pool to meet their skills needs. For instance, the Nepali Secretariat of Skills & Training has a bilateral skills partnership with Germany for energy, construction, IT sectors with 100+ students matched till 2023.

4.2

International Collaboration Opportunities

Global collaboration is essential for advancing clean energy transitions, with opportunities spanning technology exchange, financial investments, and policy alignment. These partnerships can accelerate innovation and scale the deployment of sustainable solutions worldwide.

I. Collaboration on Technology

India is increasingly turning to advanced technologies from around the world to accelerate its infrastructure development. A notable example is the collaboration between Delhi Metro and Siemens Mobility for the last 15 years, where the integration of foreign expertise has played a crucial role in the successful implementation of multiple phases of the metro system at a large scale. India is emerging as a significant global hub for Research and Development (R&D) in manufacturing, particularly in the Renewable Energy sector. Indian companies are increasingly forming Joint Ventures (JVs) with international firms, leveraging their advanced technologies to boost manufacturing capabilities in clean energy solutions. One of the most notable areas of collaboration is in Green Hydrogen production. Some examples of this collaboration:

Technology Collaborations for Green Hydrogen Production

Larsen & Toubro (L&T)

Larsen & Toubro (L&T), in partnership with McPhy Energy, is planning to set up a GigaWatt-scale electrolyzer manufacturing facility in India. This facility will utilize McPhy's advanced technology to meet the growing domestic demand for Green Hydrogen production and also serve selected international markets.

John Cockerill and GreenKo

The partnership between John Cockerill and GreenKo aims to develop a large-scale hydrogen production ecosystem in India, combining John Cockerill's pressurized alkaline technology with GreenKo's Renewable Energy capabilities to deliver low-cost Green Hydrogen.

Reliance New Energy Solar Ltd (RNESL)

Reliance New Energy Solar Ltd (RNESL) plans to establish a gigafactory in Jamnagar, Gujarat, for manufacturing Stiesdal's HydroGen Electrolyzers.
This collaboration with Stiesdal PtX Technologies aims to advance and scale up hydrogen electrolyzer technology in India.

Source: Press Search

On a broader scale, the U.S.-India Renewable Energy Technology Action Platform (RETAP) exemplifies the growing international collaboration in clean energy. Under the Strategic Clean Energy Partnership, RETAP is advancing Green Hydrogen, wind energy, and long-duration energy storage, showcasing the commitment of both nations to accelerate global clean energy transition.

These collaborations exemplify how global cooperation in technology and innovation is critical to advancing clean energy solutions and transition. To accelerate progress, nations must continue to work together, sharing knowledge and resources for a sustainable future.

India should promote collaboration for technology transfer in emerging and advanced RE technologies, backed by a standardized technology transfer framework that enables negotiation of technology transfer agreements with leading Renewable Energy nations.

Renewable Energy technology zones should also set up technology testbeds and pilot demonstration projects in partnership with global innovators, which can be incentivized by tax benefits and grants to international companies.

Policy mechanisms should also facilitate co-manufacturing partnerships with global leaders to localize production of Renewable Energy components, especially advanced or complex components.

II. Collaboration on Funding

India's energy transition efforts have gained momentum in recent years, supported by both international organizations and private sector investments. A crucial part of this progress has been the significant involvement of organizations like the World Bank, which has provided substantial funding to bolster India's Renewable Energy projects. Since 2017, the World Bank has committed $648 Mn to India's Grid-Connected Rooftop Solar Program, focusing on commercial and industrial rooftop photovoltaic systems[35].

Private sector investments and Foreign Direct Investment (FDI) flows are also pivotal in shaping India's Renewable Energy landscape. From FY2013 to FY2023, ₹88,000 crore in cumulative equity[36] FDI has flowed into India's Non-conventional Energy sector. **Companies like ArcelorMittal are investing in RE facilities, such as Greenko's projects in Andhra Pradesh. At the same time, TotalEnergies has partnered with Adani Green Energy Limited to develop a large-scale solar portfolio in Gujarat.** International investment funds are also channeling significant resources into India's Renewable Energy sector. For instance, **Singapore-based Camas Investments has made substantial equity investments in scaling up solar and wind capacities. At the same time, the Abu Dhabi Investment Authority (ADIA) has financed large-scale solar power plants and wind farms.** This exemplifies how global financing can directly drive localized Renewable Energy projects, spurring growth in the sector.

Underutilized Climate Finance Opportunities

Between 2014 and 2021, $616.5 Bn was committed globally as climate finance Official Development Assistance (ODA), as per OECD data. However, India received only 9.5% of this total, amounting to approximately $58.4 Bn. This is a relatively low share compared to the total funds committed to the Asia region, which ranged between 14% and 37% of global climate finance during the same period.

35. World Bank (2022); **36.** Mercom India (2023).

Potential to Attract Climate Financing from 8 Organizations with High Commitment in Asia

Organization	Total Commitment (2014-2021) $ Mn	Asia Commitment (2014-2021) (% of total)	India Commitment (2014-2021) (% of total)
French Development Agency	33,402.1	28%	**5%**
International Development Association (IDA)[1]	54,575.9	37%	**2%**
Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung	27,019.4	16%	**2%**
Green Climate Fund	7,769.2	25%	**4%**
Agency for International Development	8,617.6	23%	**1%**
Department for International Development	9,248.9	18%	**1%**
European Commission	26,874.9	14%	**0%**
European Bank for Reconstruction and Development (EBRD	25,391.6	26%	**0%**

Average Commitment to India **9.5%**

1. Part of the World Bank Group
Source: Organization for Economic Co-operation and Development (OECD)

This financing gap highlights an untapped opportunity for India to secure a more significant portion of climate finance from international organizations. Institutions such as the Green Climate Fund, European Commission, and the International Development Association (IDA) could be approached to more prominently include India in their climate finance portfolios.

A strategic focus on these funding sources could unlock billions of dollars in investments, accelerating India's energy transition and supporting its Renewable Energy ambitions.

III. Collaboration on Policy Alignment

As the global economy transitions towards a sustainable future, the importance of international policy alignment has become more critical than ever. In an increasingly interconnected world, where nations trade goods, services, and energy across borders, clear definitions and harmonized regulations are essential to facilitate smooth global trade. Aligning policies at the international level ensures that countries can effectively collaborate to meet shared climate goals while avoiding fragmented systems that could hinder progress.

A key aspect of this alignment is creating a transparent and consistent framework to guide governments and businesses through the transition to green energy. Two critical enablers of this transition are:

- **Green Taxonomy**
  To foster global collaboration on green energy, a worldwide green taxonomy that clearly defines what constitutes "green" in terms of products, energy, and activities is urgently needed. Such a framework would ensure consistency in how countries and companies classify sustainable initiatives, providing a common language to collaborate effectively towards shared environmental goals.

- **Carbon Markets**
  Establishing a standardized global carbon credit mechanism presents a significant opportunity with the rise of carbon markets. Harmonizing carbon pricing across export-import activities would provide transparency and fairness in international trade. As diverse systems, such as the EU's Carbon Border Adjustment Mechanism (CBAM) and various Emissions Trading Systems (ETS), continue to evolve, a unified approach would help ensure fair competition, promote sustainable economic growth, and support global efforts to meet climate targets.

IV. Collaboration on Skilling

To position India as a global Center of Excellence (CoE) for green skills, it is essential to design cutting-edge, specialized courses across Renewable Energy (RE) technologies and functions. Collaborating with leading global RE developers can provide valuable practical insights to enhance these programs. Additionally, partnerships with these companies can facilitate on-the-job skilling internships, enabling participants to build practical, industry-relevant skills effectively.

Furthermore, Government-to-Government (G2G) collaborations can be explored to develop integrated programs encompassing skilling, visa facilitation, and migration. These initiatives can address the green skills talent deficit faced by certain nations, fostering mutual benefits and strengthening international partnerships.



05

Key Takeaways & Policy Implications for India's Green Electrification

5.1

Key Takeaways for Industry Stakeholders

The Irreversible Megatrend of Global Energy Transition

- **Global climate change and India's leadership in Renewable Energy**
  India stands out as a leader in the global Renewable Energy landscape, having met its 2030 climate targets ahead of schedule and increasing its non-fossil fuel power capacity. Despite these achievements, the global community, including India, faces significant challenges in limiting warming to 1.7–1.8°C (well below 2°C as per the Paris Agreement and discussions in COP29), underscoring the need for intensified efforts to meet stringent global climate goals.

- **Crucial Role of Electricity in Decarbonization and the journey ahead**
  Electricity plays a central role in India's decarbonization strategy—Green power along with electrification of transport & industry use cases have the potential to target 55–65% of India's emissions. In line with this, India has committed to an ambitious target of 500 GW of non-fossil fuel capacity by 2030 (485 GW RE and 15 GW nuclear), which will require extensive expansions in Renewable Energy capacity, alongside substantial enhancements in electricity infrastructure and policy frameworks.

Transitioning the Electricity System

- **Ensuring storage support to manage RE induced generation volatility**
  The CEA projects ~336 GWh storage market by 2030 with demand to be driven largely by intra-day storage due to mismatch between peak RE generation (at mid-day) and peak demand slots (during early mornings and evenings).

- **At a system level—storage to remain underutilized**
  On an annualized basis, system-level storage utilization will further dip to 0.6–0.7 cycles, given high variance between peak and non-peak storage demand. Excess electrons will be available for charging only at the mid-day solar generation peak, limiting storage utilization to one cycle per day. Thus, charging & demand constraints together will limit storage utilization making it one of the most expensive elements in the electricity mix.

- **Optimizing the sizing and mix of storage resources can unlock savings**
  Storage requirement is inversely proportional to wind capacity, thermal capacity, and availability of peaking support (e.g., natural gas plants)—Hence, imperative to optimize for these levers. Potential to de-bottleneck wind capacity through innovative policy solutions for evacuation infrastructure, leverage existing underutilized captive thermal power plants (~65 GW), and drive usage of existing natural gas plants for peak-demand support. Additionally, right mix of PSP and BESS largely driven by LCOS competitiveness—currently PSP LCOS is around 20% lower than BESS, however, BESS offers higher flexibility and faster time to commissioning.

- **Need to address infrastructure constraints to drive RE installations**
  Land acquisition and evacuation/transmission infrastructure—currently emerging as major bottlenecks. Over 8 lakh acres of land will be required to setup RE projects in the next 6 years in India. Currently, developers face challenges in identifying available substation capacity to effectively locate land parcels for RE development, cumbersome land acquisition processes with multiple delays and fragmented state specific RE policies. Another major concern for developers is the high lead time required for evacuation connectivity, reporting significant delays in project commissioning.

- **8x scale-up in financing requirement to the tune of ₹30–32 lakh crores over FY24–30 versus last ten years**
  Supportive policies to drive international financing will be critical to meet this massive financing gap and bolster domestic capital markets & financial institutions. It is imperative to attract international financing with a focus on a national green taxonomy aligned with the global taxonomies. Further, domestic capital markets & financial institutions can be oriented towards green sectors through RE investment mandates and strategic exemptions.

Electrification Use Cases for Transport and Industrial Decarbonization

- **Electrification applications can drive significant decarbonization in the transport sector**
  Transportation contributes to ~13% of India's total CO_2 emissions with ~90% coming from road transportation. EVs are a mature decarbonization alternative with potential to reduce ~50% CO_2 emissions for each ICE vehicle replaced. By FY30, EVs are projected to constitute 30–35% of new vehicle sales in India (reducing transport emissions by 3–4%) vs current 7%—Potential to draw on learnings from early adopters such as Norway and US. However, from an electrification perspective, EVs to comprise only ~1% of electricity demand.

- **Green Hydrogen's decarbonization potential could make it the gold standard of future fuels**
  Green Hydrogen presents a critical opportunity for decarbonizing heavy industries and refining processes with ~84% reduction in CO_2 emissions versus Grey Hydrogen. Additionally, Green Hydrogen can provide energy security and import bill reduction (by replacing natural gas). Further, India is competitively placed to become global Green Hydrogen export hub given low cost of RE generation and expected advantages in electrolyzer manufacturing. India has a promising start—with supportive policies and some ammonia offtake tenders already in place—Potential to drive export impetus via G2G collaborations.

- **Electrifying industrial processes across key energy-intensive industries like Iron & Steel and Cement**
  Iron & Steel—one of the country's high-emissions sectors—with ~12% of total emissions has significant potential to adopt green electrification and Green Hydrogen to reduce emissions by 55%. Further, another high emitting industrial sector—Cement—can reduce up to 44% emissions via green electrification and waste heat recovery processes. However, these electrification pathways are still fairly cost intensive—hence higher focus on R&D and industry collaboration is needed to achieve economically viable solutions.

- **Leveraging Carbon Markets for Industrial Decarbonization**
  Implementing carbon pricing mechanisms such as carbon markets and taxes is crucial to incentivize industries to adopt low-carbon technologies—CCUS policies are already underway in India. By establishing financial incentives for reducing emissions, carbon markets can drive investment in cleaner production methods and align industry practices with global climate commitments. Further, to retain export competitiveness—as carbon limits such as CBAM in the EU are enacted for emissions-intensive industries, particularly steel and cement—India will need to consider greening of its industrial sectors. For instance, the estimated carbon penalty for India's steel exports is expected to be between €170–180 per tonne of crude steel, based on an assumed carbon price of €100 per tonne under the EU ETS.

Unlocking an Enabling Environment for Green Power Transition

- **Building green skills can enable India to lead the energy transition**
  Green energy is expected to create around 3 Mn jobs in India by 2030—with training across right skills critical for workforce effectiveness. Further, global shortage of 7 Mn green energy workers is estimated by 2030—presenting an opportunity to India to position itself as a global supplier of green talent. In this scenario, proactive initiatives for skilling are imperative to capture this opportunity and ensure smooth transition to a green economy.

- **International collaboration across technology, financing and policy harmonization can bring about a cohesive green and global future**
  Potential to drive R&D via collaboration with government think tanks (e.g., RE-TAP partnership between India and the US for shared innovation and investment in Green Hydrogen, wind energy, and storage) as well as private sector joint ventures (e.g., partnership between John Cockerill and Greenko to scale Green Hydrogen production in India). Further, potential to draw investment through targeted initiatives to attract capital from private sector investors and DFIs. Going forward, harmonizing of India policies with global standards will be critical to facilitate global investments (e.g., Green taxonomy) and global trade (e.g., Carbon trading).

  The subsequent section delves into policy solutions addressing the primary challenges encountered in advancing green electrification for India's energy transition journey.

Policy Action Recommended Across 8 Key Areas

I. Policy recommendations to optimize storage requirement & facilitate market shaping

- **Potential to optimize storage capacity sizing via**
  - **Boosting wind capacity by de-bottlenecking evacuation constraints via**
    - Reserving capacity at high-wind sites.
    - Augmenting substation capacity with storage.
    - Offering financial incentive for solar project developers to share evacuation infrastructure with new wind projects.
  - **Utilization of existing C&I Thermal plants to expand power capacity—**refurbishment, modernization & takeover of operations by State owned thermal power entities like NTPC.
  - Calendarized tenders for **peak power supply via existing natural gas plants** offering visibility to developers anchored on precise forecasting method.

- **Development of power markets to capture right economic signals**
  - RE Tender structures in formats reflecting true variations in intra-day & seasonal demand.
  - Market for Storage and ancillary services trading which can offer flexible avenues for grid management.

- **Implementation of Real-time power pricing or time-of-day pricing to incentivize demand smoothening.**

- Facilitation of PSP installations via **National level body to expedite PSP project approvals** offering clear playbook for project developers and single window clearance assistance.

II. Policy recommendations to expedite land, evacuation & offtake for RE projects

- **Streamlined land identification & acquisition** via
  - **State-wise clear land acquisition playbook** hosted online with connect to district level task force to expedite land approvals at local tehsil.
  - **Deemed land conversion polices** with RE classification expediting approvals.
  - **Targeted financial & non-financial incentives enabling RE under-indexed states** to offer similar LCOE as RE-rich states (feasible with low module prices & enhanced PLF), to offset spiraling land costs in RE-rich states.
  - Establishment of **State-level Nodal offices for land acquisition** & transmission RoW offer a package to developers, especially with support of local Revenue department.

- **Expedited development of grid infrastruct** via
  - **Synchronized transmission capacity planning** with 2-3 years lead time to RE generation leveraging right forecasts.
  - **National online portal to track available & upcoming sub-station capacity** for clarity on project siting.
  - **Elimination of transmission equipment bottleneck** via aggregated order placement for equipment, interim BTM BESS augmentation at high-load sites, and domestic manufacturing of equipment.
  - **Encouraging private player participation in transmission development** in PPP mode with state offering RoW approval support.
  - Offering **financial incentives to states for participation in ISTS connected projects.**

- **Incentives for DISCOMs to sign PPAs**
  - **Uniform National RE tariff** with blended tariffs across PPAs disincentivizing delay in PPA signing due to expected decrease in tariff.
  - **Stringent adherence to RPO** with strict penalties for non-compliance.

III. Policy recommendations to drive RE financing across funding sources

- **Mobilization of global funds towards India's RE sector via**
  - Clear Green Taxonomy with globally harmonized standards.
  - Government led reach-outs to DFIs to build awareness for financing opportunities in India, especially for DFIs with significant presence in Asia but under-indexed in India.
  - Removing or reducing the withholding tax on foreign-currency bonds floated by Indian RE developers or RE financing institutions.

- **Development of thriving domestic "green" investment market across**
  - **Capital markets** via upto 5% AUM obligation for domestic pension & insurance funds with potential to unlock over ₹3–4 lakh crores+.
  - **Banks** can be obligated to expand RE quota under Priority Sector Lending (PSL) or investment in green bonds (Renewable Finance Obligations) to enhance their currently limited play in green sectors.
  - **NBFCs,** currently supporting over 33% of RE financing, can be empowered via net-worth linked exemptions as well as increased allocation of low-cost 54 EC bonds.

IV. Policy recommendations to develop India's e-mobility ecosystem

- **Drive ease of financing for EVs via**
  - Inclusion of commercial EV loans under **Priority Sector Lending** enhancing fund flow to the segment.
  - **De-couple battery & vehicle (with separate ownership documents) to facilitate leasing/ swapping/pay-per-use models**, thereby enabling flexible financing structures.
  - **Establish battery safety standards** & performance certification framework enabling upfront clarity on resale value.

- **Offer disincentives for ICE usage & incentives for EV usage, e.g.,** Norway taxed ICE vehicles (fossil fuel tax & higher road tax) while offering financial exemptions for EVs (toll exemption, free parking, VAT waivers, etc.).

- **Develop extensive network of standardized charging infrastructure, led by OEMs in PPP mode (using govt land) & public maps with data on available chargers.**

V. Policy recommendations to catalyze Green Hydrogen ecosystem in India:

- Drive G2G collaborations for offtake targeting net importer regions such as **Japan, Korea, the Middle East and the European Union** to build critical mass of offtakers, thereby catalyzing ecosystem development & economies of scale across production & infrastructure.

- Develop **robust manufacturing ecosystem across electrolyzer components with strategic incentives for high-value components (e.g., power systems)—**digital platform can also be created to link players across the value chain.

- **Promote R&D with well-defined targets** such as minimizing loading of rare metals not available in India and developing advanced membrane technologies to reduce import dependence.

- **Initiate proactive planning for transmission infrastructure at identified Green Hydrogen Hubs,** in addition to steps to augment RE capacity.

- **Establish harmonized grid connectivity standards for electrolyzers** as well as appropriate financial incentives to leverage electrolyzers to manage solar curtailment as well as grid balancing.

- **Establish robust Green Hydrogen standards** harmonized with global standards, and establish robust, objective & practical certification framework.

- **Targeted policies to unlock Hydrogen Fuel Cell Vehicle adoption at scale in India** spanning R&D on manufacturing indigenization and cost efficiencies for fuel cells and refueling stations, strategic support to build local manufacturing ecosystem as well as clear targets for FCV adoption and fueling station by 2030 to drive capex efficiencies.

VI. Policy recommendation to expedite industrial decarbonization

- **Establish clear standards and certification framework** in line with global standards (e.g., CBAM in EU) for what constitutes "Green"- e.g., Ministry of Steel has recently released a Taxonomy for Green Steel with defined emissions intensity across different sustainability grades. Also, there will be a need to create training program for independent auditors, who can offer these emissions validation & certifications.

- **Promote R&D leveraging international collaboration** to achieve financial feasibility for Carbon Capture, Utilization and Storage (CCUS) technologies to drive emissions reduction in hard to abate sectors—e.g., Cement BF-BOF Steel, etc.

- **Offset CCUS costs** by establishing mandates for utilization of captured carbon in downstream applications as well as carbon trading, creating additional revenue streams.

- **Create critical anchor set of offtakers via G2G collaborations as well as mandate for certain share to be used for domestic government infrastructure projects.** This will provide the impetus for ecosystem development as well as drive economic viability for initial infrastructure investments.

VII. Policy recommendations to capitalize on the green skills gap

- **Establish Green Skilling "Centers of Excellence"** providing comprehensive courses in line with skill requirement for each "green" job family, in line with global standards & leveraging global partnerships- targeting freshers as well as reskilling of professionals in carbon–intensive industries impacted by green transition.

- **Position India as a "global green talent hub"** via integrated training, visa and migration partnerships with countries seeking green talent such as Australia.

- **Facilitate job matching** by creating portal for "green jobs" certification and job posting linking trainees with the right job opportunities.

VIII. Policy recommendations to drive collaboration

- **Promote collaboration for technology transfer** (especially emerging RE technologies) via a standardized Technology Transfer Framework, set up technology testbeds and pilot demonstration projects in partnership with global innovators, and enable co-manufacturing and global supply chain integration for advanced components.

- **Promote international funding as part of global RE investment meetings** through targeted reach-out to global pension funds, sovereign wealth funds, and DFIs for driving green investments in India.

- **Develop a harmonized global "Green Taxonomy"** that clearly defines what constitutes "green" in terms of products, energy, and activities, and **establish a standardized global carbon credit mechanism** to harmonize carbon pricing and enhance transparency.

- **Promote collaboration for establishing India as a skilling CoE** and G2G agreements with green workforce deficit nations for integrated visa migration programmes fostering mutual benefit.

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