ASIAN DEVELOPMENT BANK

Annex 2

Feasibility study

2 June 2025

This feasibility study assesses the market landscape for the India Green Finance Facility (IGFF) and evaluates the potential impact of the proposed program. It serves two key objectives: (i) ensuring that IGFF's interventions align with India's climate goals and market needs, and (ii) establishing the additionality of Green Climate Fund (GCF) support, demonstrating how concessional finance can catalyze systemic shifts in clean energy investment.

The study is structured to systematically address the "What," "Why," and "How" of IGFF's approach. It begins with an assessment of India's climate and energy landscape, covering emission sources, climate risks, and national commitments. The next section evaluates India's clean energy transition, mapping progress, identifying key technology needs, and analyzing the current finance ecosystem while highlighting barriers to scaling investments in emerging clean energy technologies.

The study then focuses on the role of domestic Development Finance Institutions (DFIs) as primary vehicles for IGFF's implementation. It examines their potential to mobilize and channel green finance, provides detailed profiles of the DFIs shortlisted for IGFF's initial phase, and identifies areas where their capacity must be strengthened to scale green lending effectively.

The final sections outline IGFF's targeted technology interventions, presenting a structured assessment of priority technologies and applications within the scope of the facility. This also includes an indicative pipeline of the risk-sharing facility proposed under the facility, as well as complementary programs and interventions that reinforce IGFF's objectives.

By integrating these insights, the feasibility study provides a clear rationale for IGFF's design and implementation, ensuring its alignment with India's clean energy transition while strengthening the role of domestic financial institutions in delivering climate-aligned investments.

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1. India's Climate and Energy Landscape

1. **This chapter establishes the energy and climate baseline for India, identifying the key areas where IGFF can drive impact.** It first examines the relationship between development, energy access, and demand, assessing both present trends and future needs in alignment with India's growth priorities. It then evaluates India's greenhouse gas emissions profile and maps the key climate risks—both physical and transitional—that threaten energy security and access. The chapter further outlines India's clean energy commitments, assessing progress made and the risks of delayed implementation, such as carbon lock-in and economic vulnerabilities. It concludes by identifying the priority sectors—energy, industry, transportation, and agriculture—that offer the greatest potential for IGFF's interventions, ensuring its focus aligns with India's transition goals while enhancing resilience and economic stability.

1.1 The development-energy sector nexus

2. **India's ambition to become the world's third-largest economy by 2030, coupled with a rapidly growing population, places poverty alleviation, job creation, and infrastructure expansion at the forefront of its developmental agenda.** As the world's most populous country, India is home to 18% of the global population, with a density of approximately 473.2 persons per square kilometre. Urbanization in India is accelerating, with the urban population expected to reach 675 million by 2035 (~43% of the total) and expand further by 2.2 billion by 2050, reaching approximately 68% of the current global population, assuming a steady annual growth rate of 2.4%. Economic growth remains robust, with a GDP growth rate of 7.8% in 2023, positioning India among the world's fastest-growing major economies. Over the past decades, significant strides have been made in poverty reduction—between 2005-06 and 2019-21, 415 million people exited poverty. However, challenges persist – as of 2022, 16.4% of the population remains multidimensionally poor, with an additional 18.7% classified as vulnerable to multidimensional poverty.[1] Wealth inequality remains stark—while one-tenth of the employed population survives on less than USD 1.90 per day, the top 10% of Indian households hold 77% of the nation's wealth (Table 1).

Table 1. Key Socio-economic Indicators for India

Indicator	Value
Population Undernourished	14.0% (2017-2019)
Proportion of Employed Population Below $1.90 PPP a Day	10.7% (2019)
Share of National Wealth Owned by Top 10% of Households	77% (2020)
Net Annual Migration Rate	-0.04% (2015-2020)
Infant Mortality Rate (Between Age 0 and 1)	3.2% (2015-2020)
Average Annual Change in Urban Population	2.4% (2015-2020)
Dependents per 100 Independent Adults	48.7 (2020)
Urban Population as % of Total Population	34.9% (2020)
External Debt Ratio to GNI	19.3% (2018)
Government Expenditure Ratio to GDP	13.7% (2019)

Source: World Bank, 2021

3. **At the same time, India's energy needs play a pivotal role in determining the trajectory of its human development.** The relationship between final energy consumption and the Human Development Index (HDI) underscores the scale of energy-related efforts required for India to transition from a medium-HDI country

[1] Multidimensional poverty refers to the various deprivations that individuals face in health, education, and standard of living and is measured using ten indicators, including nutrition, child mortality, years of schooling, school attendance, access to cooking fuel, sanitation, drinking water, electricity, housing, and asset ownership; UNDP, "2024 Global Multidimensional Poverty Index (MPI): Poverty Amid Conflict", 2024.

(0.633) to an advanced and inclusive economy by 2047, as envisioned in the Amrit Kaal framework.[2] Countries with an HDI exceeding 0.9—such as those in the top 28 global rankings—have significantly higher per capita energy consumption. In fact, energy demand increases disproportionately as countries move from an HDI of 0.8 to 0.9, compared to the transition between 0.7 and 0.8. This means that achieving India's developmental ambitions will necessitate significant improvements in energy access, efficiency, and sustainability while ensuring affordability and equity.

4. **Energy access and security is fundamental to industrial expansion, rural electrification, and urbanization — key drivers of economic progress and improved quality of life**. Despite energy use doubling since 2000, India's per capita energy consumption remains less than half the global average, reflecting both its vast potential for growth and the scale of unmet demand. Sustained economic growth, fuelled by rapid industrial and urban growth, rising incomes, and improvements in living standards are expected to drive higher energy consumption. By 2035, total energy demand is projected to rise by nearly 35% of current levels, with electricity generation capacity needing to triple to 1,400 GW to keep pace under a Stated Policies Scenario (STEPS) scenario.[3] In 2024 alone, energy demand grew by 5.8% year-over-year and is expected to accelerate to an average of 6.3% annually over the next three years. Despite the rising demand, energy access remains deeply uneven, particularly in rural areas that house a significant number of poor households. A 2016 study across six of India's most energy-deprived states found that while over 90% of villages were electrified, only 63% of households had a grid connection, and just 37% received adequate electricity.[4] This is amidst India achieving near-universal electricity access, increasing from 60% to 99% of the population between 2000 and 2022, accompanied by a 182% increase in electricity consumption per capita in the same period.[5] Many poor households, deterred by high costs of electricity and unreliable supply, remain disconnected, limiting their ability to access economic opportunities. Hence measures to increase energy access in an affordable and reliable manner, along with increasing energy output to meet the rising demand, is a priority for the country.

5. **Coal remains central to India's energy system, sustaining key sectors despite growing clean energy investments.** In 2023, India's total primary energy supply stood at 847 million tons of oil equivalent (Mtoe), with coal dominating at 59.34%, followed by oil (28.99%) and natural gas (6.45%). Renewables and nuclear energy contributed less than 3% (Figure 1)[6]. Industry remains the largest energy consumer, accounting for over 40% of demand, particularly in energy-intensive sectors like steel, cement, and aluminum. Transport relies overwhelmingly on oil (92%), while traditional biomass (59%) remains a primary energy source for rural households. In agriculture, electricity accounts for 98% of energy use (Figure 2)[7]. Coal's role in India's energy strategy is unlikely to diminish in the near term, given the imperative to meet rising energy demand while supporting economic growth. The country has witnessed the highest-ever coal production in the year 2023-24, with the Ministry of Coal aiming to increase coal production to 1.31 billion tons by FY25 and 1.5 billion tons by 2030.[8] Under the current stated policies scenario for India, IEA forecasts nearly 60 GW of coal-fired capacity additions net of retirements by 2030, with its share in electricity generation rising by over 15% compared to current levels.[9] In 2022, coal's contribution to total electricity generation stood at 72%. The sector also has deep economic linkages, employing 443,000 people, accounting for nearly 50% of rail freight revenue, and generating INR 70,000 crore (USD 8.5 billion) in taxes and levies.[10] Despite India's clean energy push, fossil fuel investments remain significant. In 2023, clean energy investment surged to USD 68 billion—40% higher than the 2016-2020

[2] Press Release: Press Information Bureau; POSITIONING INDIA FOR THE FUTURE: THE AMRIT KAAL BUDGET – India Foundation
[3] https://www.iea.org/reports/world-energy-outlook-2024
[4] CEEW, "Measuring Energy Access in India", 2016; The survey that underpins the findings of the study covered rural areas of the following six states – Uttar Pradesh, Bihar, Jharkhand, Odisha, West Bengal, and Madhya Pradesh. These are also incidentally some of the most populous states in the country.
[5] World Bank, "Access to electricity (% of population) – India", accessed June 2023; IEA, "India: Energy system of India", accessed in February 2025.
[6] NITI Aayog, "India Climate and Energy Dashboard", accessed in January 2025.
[7] IEA, "India", accessed in January 2025.
[8] https://pib.gov.in/PressReleasePage.aspx?PRID=2088467#:~:text=The%20Ministry%20of%20Coal%20has%20set%20a%20goal%20to%20produce,coal%20with%20locally%20mined%20coal.
[9] https://www.iea.org/reports/world-energy-outlook-2024
[10] https://www.ey.com/content/dam/ey-unified-site/ey-com/en-in/insights/energy-resources/documents/2024/ey-energy-transition-india-s-journey-to-net-zero.pdf

average—but fossil fuel investments also grew by 6%, reaching USD 33 billion.[11] This underscores the complexity of India's energy transition, where coal remains a pillar of energy security and economic stability.

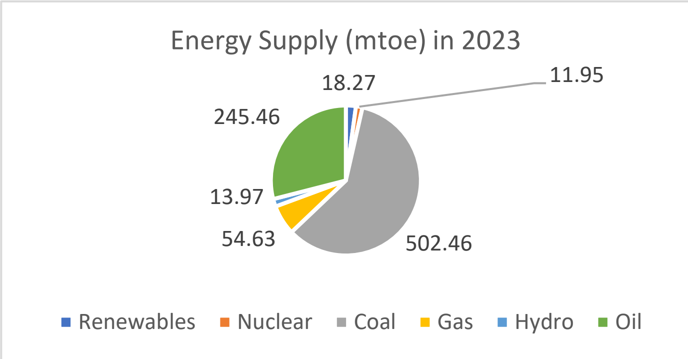


Figure 1. Primary energy supply in India, 2023

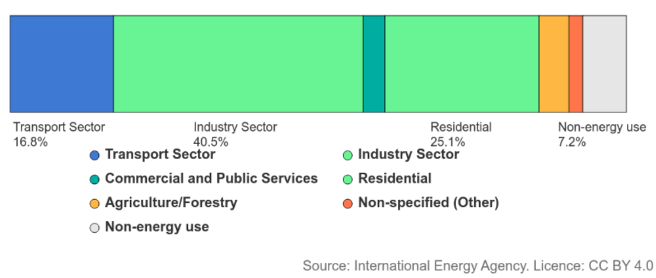


Figure 2. Total final energy consumption by sector, India, 2022

1.2 India's GHG emission profile

6. **India's rising emissions are driven by economic growth and heavy fossil fuel dependence, despite its historically low per capita contributions.** Although India's per capita energy consumption is just 25.4 GJ—far below the global average of 78 GJ—its vast population and fossil fuel-intensive economy make it the world's third-largest emitter.[12] However, between 1850 and 2019, India accounted for only 4% of global emissions, and its per capita emissions (2.48 tCO_2 per person) remain the lowest in the G20—about one-eighth of the average American's emissions.[13] These figures highlight India's historically modest contribution to climate change, despite its current ranking as a major emitter.

7. **Rapid industrialization has driven a sharp rise in emissions, with the energy sector dominating India's carbon footprint.** Between 1994 and 2020, total GHG (CO_2e) emissions grew by 144%, while net emissions—after accounting for carbon sinks from land use, land-use change, and forestry (LULUCF)—rose by 98.34%. A notable 7.93% decline in net emissions occurred between 2019 and 2020 due to the economic slowdown from the COVID-19 pandemic. In 2020, total emissions stood at 2.96 billion Gg CO_2e, with net emissions reducing to 2.44 billion Gg CO_2e after LULUCF adjustments (Table 2; Figure 3).

Table 2. Sector-wise National GHG emissions in Gg for 2020

GHG sources and removals	CO2 emission	CO2 removal	CH4	N2O	HFC 23	CF4	C2F6	SF6	CO2 equivalent	CO2eq (in %), excluding LULCF	CO2e equivalent (in %),

[11] IEA, "World Energy Investment 2024", 2024.
[12] Ministry of Environment, Forest and Climate Change, "India: Fourth Biennial Update Report to the United Nations Framework Convention on Climate Change", 2024.
[13] Climate Watch | World Resources Institute

											incl. LULCF
Energy	2181012	NO	1523	82	NO	NO	NO	NO	2238409	**75.66%**	**91.86%**
IPPU	201044	NO	232	8	2	1	0.27	0.004	238556	**8.06%**	**9.79%**
Agriculture	NO	NO	14290	342	NO	NO	NO	NO	405983	**13.72%**	**16.66%**
LULUCF	9369	-532357	41	1	NO	NO	NO	NO	-521933	**-17.64%**	**-21.42%**
Waste	NO	NO	2726	58	NO	NO	NO	NO	75641	**2.56%**	**3.10%**
Memo Items	802846	NO	0.09	0.11	NO	NO	NO	NO	802882	**27.14%**	**32.95%**
Total Emission	**2382535**	**--**	**18771**	**489**	**2**	**1**	**0.27**	**0.004**	**2958589**		
Net Emission	**2391904**	**-532357**	**18811**	**490**	**2**	**1**	**0.27**	**0.004**	**2436656**		

Source: MoEF&CC, 2024

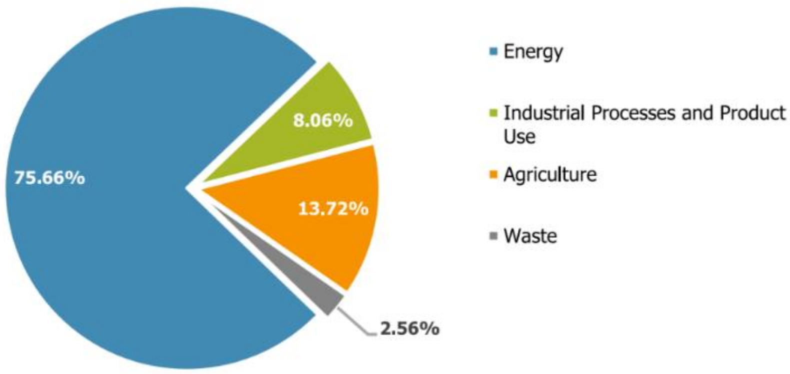


Figure 3. Distribution of GHG emissions (GgCO2e) by sector, 2020

8. **Fossil fuel dependence poses a long-term carbon lock-in risk, with emissions projected to steadily rise until at least 2040 under the BAU scenario.** Under current policies, India's emissions are expected to keep increasing beyond 2030, peaking between 2035 and 2040. According to BloombergNEF's (BNEF) 2.6°C scenario, energy-related emissions are projected to rise by 21% between 2022 and 2050, primarily due to surging demand in the power and industrial sectors (Figure 4). Coal consumption is expected to peak in 2037 at 1,098 million metric tons (Mt) before declining slightly to 970 Mt by 2050—still 20% above 2021 levels. Oil use is projected to peak in 2038 at 270 million tons of oil equivalent (mtoe) before dropping marginally to 249 mtoe by 2050, a 28% increase from 2021. The sustained reliance on fossil fuels for economic growth and energy security risks reinforces a carbon lock-in effect, increasing India's GHG emissions and delaying India's transition to a low-carbon economy.

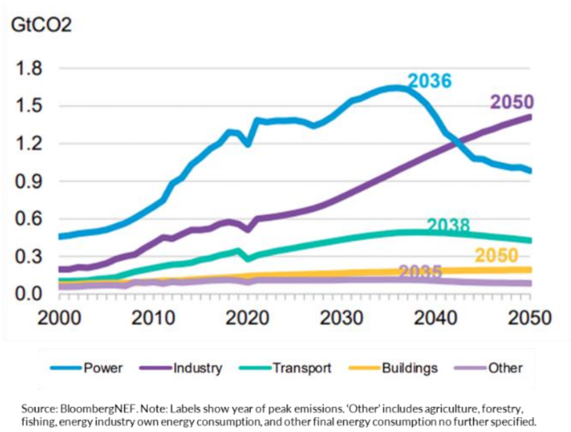


Figure 4. Projections for India's emission profile for India until 2050 (baseline scenario)

1.2.1 Key contributing sectors and sources

9. **The energy sector was the largest contributor to the country's GHG emissions profile in 2020, accounting for 75.66% of emissions, followed by agriculture (13.72%), industrial processes and product use (8.06%), and waste (2.56%).** Within the energy sector, electricity generation alone accounted for 40% of national emissions, with road transport contributing another 9% (Box 1).[14] As of 2022, energy-related CO2 emissions from India contributed to 7.38% of the global emissions.[15] The following sections outline the most energy-intensive and emissions-heavy sectors in India, including the energy sector, highlighting their structural dependencies on fossil fuels, the risks of inaction, and the interventions needed to drive a low-carbon transition.

10. **Energy is the largest contributor to India's emissions, with electricity generation alone accounting for 40% of national emissions.** Despite increasing clean energy investments, fossil fuels still supply over 75% of electricity, reinforcing structural dependencies on coal, oil, and gas. Ensuring reliable, affordable, and sustainable energy access is crucial for economic growth, industrial productivity, and improved quality of life. Without interventions to scale non-fossil energy and modernize grid infrastructure, India risks entrenching its current reliance on high-emission energy sources to support the projected rise in energy demands, including for electricity supply, delaying its transition to a cleaner energy system.

11. **Industries such as steel, cement, and chemicals are among the most energy-intensive and high-emitting sectors, relying on coal for thermal energy and industrial processes.** The manufacturing sector alone contributed 17.45% of energy sector emissions in 2020, with iron and steel accounting for nearly 39% of those emissions. These industries are critical to job creation and economic output, but their high fossil fuel dependence makes them vulnerable to rising energy costs and an evolving landscape of carbon pricing mechanisms, reducing their competitiveness. Addressing emissions in this sector is hence also essential to ensuring global competitiveness and sustainable industrial growth.

12. **Transportation is 92% dependent on oil, making it one of the critical sectors to decarbonize, while also being a major source of air pollution.** Road transport alone contributes 9% of India's total emissions and is the second-largest emitting category after electricity generation. Additionally, transportation is a leading contributor to air pollution, responsible for 40% of PM2.5 emissions in major Indian cities and significantly worsening nitrogen oxides (NOx) and carbon monoxide (CO) pollution. These emissions have severe public health and economic consequences, reducing productivity and increasing healthcare costs. The sector's heavy reliance on imported fossil fuels also raises concerns about energy security and price volatility, making a shift towards cleaner fuel alternatives critical for reducing emissions, stabilizing energy supply, and improving urban air quality.

13. **Agriculture, while not traditionally seen as one of the highest energy-consuming sectors, holds immense potential for driving a low-carbon rural transformation that aligns with India's developmental priorities.** The sector relies on electricity for 98% of its energy needs, primarily for irrigation, cold storage, and on- and off-farm mechanization. However, in areas where grid electricity remains unreliable, diesel-powered irrigation pumps and generators are widely used, contributing to fugitive emissions, including methane, nitrous oxide, and black carbon, which worsens air pollution and accelerate climate impacts (Box 1). Transitioning towards clean energy solutions in agriculture and

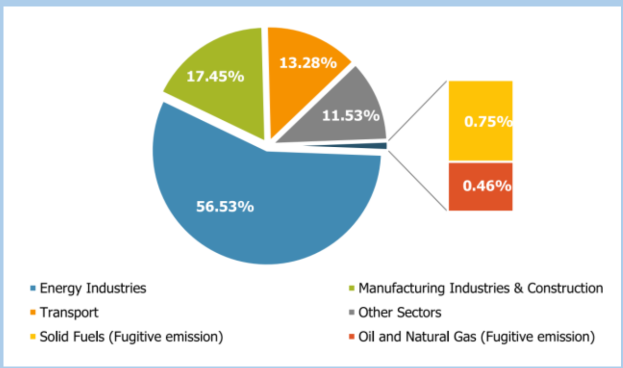
[14] India. Biennial update report (BUR). BUR 4. | UNFCCC
[15] https://www.iea.org/countries/india

allied rural sectors offers a unique opportunity to reduce fossil fuel dependence while improving rural incomes and livelihoods.

Box 1 - Energy sector emissions – current trends and future trajectory

The energy sector, including fossil fuel consumption and fugitive emissions, is the largest source of greenhouse gas emissions in India. Electricity production alone accounts for 40% of national emissions, making it the highest-emitting category, followed by road transportation at 9%. In 2020, emissions from the energy sector totalled 22,38,409 Gg CO2e, reflecting a 5.72% decrease compared to 2019, largely due to the economic slowdown caused by the COVID-19 pandemic. These emissions were predominantly driven by fossil fuel combustion across the energy sector, manufacturing, transportation, and other industries. Within the energy sector, emissions were concentrated in three key areas:

1. **Energy industries:** This category includes GHG emissions from fossil fuel combustion for energy production and fuel extraction. It accounted for 56.53% of total energy sector emissions, with electricity and heat production alone contributing 92.59% of emissions within this subcategory. Petroleum refining and the manufacture of solid fuels and other energy industries contributed 6.72% and 0.69%, respectively. Electricity production is the largest emitting category in India, responsible for approximately 40% of total national emissions (excluding LULUCF). Under a business-as-usual (BAU) scenario, electricity generation from coal is projected to increase by over 15%, remaining more than 30% higher than solar PV generation, despite solar capacity being twice as large.
2. **Manufacturing and construction:** This category covers GHG emissions from fossil fuel combustion in industrial processes, including power and heat generation for in-house use. It accounted for 17.45% of energy sector emissions, with iron and steel contributing 38.76%, followed by cement at 12.75%, both heavily reliant on coal and fossil fuels for high-temperature heat production. By 2035, iron and steel production is projected to grow by 70%, while cement output is expected to rise by nearly 55%, significantly increasing emissions if current processes remain unchanged. The dependence on high-temperature, continuous operations and fossil-based feedstocks makes these industries particularly difficult to decarbonize, reinforcing their classification as hard-to-abate sectors where alternative solutions remain costly and technologically complex.
3. **Transportation:** This category includes GHG emissions from fossil fuel combustion in all modes of national transportation, excluding military operations. It accounted for 13.28% of energy sector emissions, with road transport dominating at 94% of the total, followed by civil aviation (4%), railways (1%), and water-borne navigation (1%). Road transportation was the second-highest emitting category in India, contributing 9% of total national emissions, second only to electricity production. Over the next decade, the country is expected to add over 37 million cars and over 75 million two/three wheelers to its roads. At the current rate of internal combustion engine (ICE) and electric vehicle (EV) adoption under a Stated Policies Scenario, emissions from road passenger transport are projected to increase by 30% by 2035.



Data source: MoEF&CC, Government of India, 'India fourth biennial update report to the UNFCCC', 2024; IEA, 'World Energy Outlook 2024', 2025.

Box 2 - Emissions from irrigation pumps in India

Agriculture's energy use is predominantly electricity-driven, powering on-farm irrigation, post-harvest processing, and allied off-farm activities, accounting for 92% of its total energy consumption. As of 2020, India had 20.3 million grid-powered irrigation pumps (63.8%), 8.8 million diesel-powered pumps (27.7%), and 2.7 million solar-powered pumps (8.5%), according to estimates by the IEA. While the share of solar-powered pumps is growing, the continued dependence on diesel and fossil-fuel-powered grid electricity remains a major emissions concern. In 2013-14, groundwater irrigation alone emitted 45.3–62.3 MMT of carbon annually, contributing 8–11% of India's total carbon emission with deep tubewells having a significantly higher carbon footprint. Beyond CO_2 emissions, diesel-powered pumps are a major source of black carbon, a potent short-lived climate pollutant that exacerbates air pollution and accelerates glacial melt. In the Indo-Gangetic Plain, black carbon emissions have quadrupled between the late 1980s and 2013-14, contributing to the worsening of regional air quality. The sector's reliance on diesel and coal-powered grid electricity for irrigation underscores the urgent need for cleaner energy alternatives to power rural applications, both on- and off-farm. Without targeted interventions, the continued use of high-emission irrigation systems will not only worsen air quality and contribute to climate risks but also reinforce fossil fuel dependence in rural areas, hindering India's broader energy transition and rural transformation efforts.

Data source: IEA, 'Estimated stock of agricultural irrigation pumps in India, 2010-2022', 2020; CGIAR, 'Carbon footprint of India's groundwater irrigation', 2020.

1.3 Impacts of climate risks on India's energy and economy

14. **India's energy infrastructure is increasingly exposed to both physical and transition risks as climate change impacts intensify, and the global energy systems decarbonize.** Rising temperatures, shifting rainfall patterns, and extreme weather events are already disrupting energy production, transmission, and consumption, threatening the reliability, affordability, and accessibility of power supply (refer to Appendix 1 for a comprehensive overview of India's physical climate risk landscape). Addressing these risks requires strategic energy investments in solutions that diversify energy sources, improve grid stability and bolster climate resilience across sectors.

15. **Physical risks—such as water shortages, heatwaves, and extreme weather events—are placing significant strain on India's energy infrastructure, creating ripple effects across industries, transportation, and agriculture. If left unaddressed, these disruptions threaten economic growth and long-term energy security.** Hydropower and thermal power plants, which together account for nearly 70% of electricity supply, are increasingly vulnerable to erratic monsoons and declining water availability, leading to periodic generation losses. Between 2013 and 2016, thermal power generation losses due to water shortages totalled 30 TWh—about 2% of India's annual electricity consumption.[16] Additionally, cyclones, floods, and extreme heat events are damaging transmission lines and substations, causing widespread blackouts, as seen during the 2018 Kerala floods and the 2024 Jaisalmer heatwave, where grid infrastructure failed under extreme temperatures.[17] Meanwhile, rising peak energy demand due to increased cooling requirements is putting further pressure on the grid—Delhi recorded an all-time high power demand of 8,302 MW in May 2024, marking a 12-day streak of peak loads exceeding 7,000 MW, compared to just one such instance in 2023.[18] Beyond the direct impacts on energy infrastructure, these disruptions affect energy-intensive sectors, deepening economic vulnerabilities. Steel, cement, and chemicals—industries that depend on stable power and high-temperature thermal processes—face operational risks from heatwaves, water shortages, and grid instability, as seen in 2019 when JSW Steel cut

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[16] https://www.wri.org/insights/droughts-and-blackouts-how-water-shortages-cost-india-enough-energy-power-sri-lanka#:~:text=Our%20analysis%20found%20that%2C%20in,percent%20of%20India's%20annual%20consumption.
[17] Windmill catches fire in Jaisalmer due to extreme heatwave | Jaipur News - Times of India (indiatimes.com)
[18] Delhi Weather and AQI Today: Warm start at 28.95 °C, check weather forecast for July 10, 2024 | Latest News Delhi - Hindustan Times

production by 40% in Karnataka due to drought-related water shortages.[19] The transport sector, heavily reliant on oil-based fuels, also faces rising costs from extreme heat reducing vehicle efficiency and increasing cooling requirements, while contributing significantly to urban air pollution.[20] Meanwhile, agriculture—where 98% of energy use comes from electricity—relies heavily on stable power for irrigation, mechanization, and cold storage. Climate-induced power disruptions increase the reliance on diesel-powered pumps and generators to support on- and off- farm activities, further driving emissions while deepening rural energy insecurity.

16. **Alongside these physical risks, transitional risks tied to India's decarbonization push introduce financial and policy uncertainties.** Over 75% of India's electricity generation still comes from fossil fuels, exposing the economy to fuel price volatility, supply chain risks, and financing constraints as international climate policies tighten funding for coal-based infrastructure. As major trading partners implement stricter climate regulations, delaying the transition could erode India's industrial competitiveness in global markets. The European Union's Carbon Border Adjustment Mechanism (CBAM), which imposes tariffs on carbon-intensive imports, poses a direct risk to India's steel, cement, and aluminum exports. If industries fail to decarbonize quickly, they will face higher compliance costs, reduced export opportunities, and potential market exclusion in regions adopting stringent carbon pricing policies.[21] Additionally, access to international climate finance is increasingly contingent on decarbonization commitments, meaning that industries that do not align with low-carbon pathways risk being locked out of concessional financing and favorable lending terms for modernization and expansion. The financial sector itself is also exposed to transition risks—as global capital markets adopt climate finance taxonomies and reporting frameworks such as the Task Force on Climate-related Financial Disclosures (TCFD) and the EU Sustainable Finance Disclosure Regulation (SFDR), Indian financial institutions that fail to integrate climate risk assessments, sustainability-linked lending criteria, and enhanced disclosure mechanisms risk losing access to international financing and facing higher borrowing costs. Without proactively adapting to these changes, both industries and financial institutions could become increasingly isolated from global green finance flows, limiting India's ability to fund its clean energy transition at scale.

17. **To address these physical and transitional risks, clean energy interventions must prioritize solutions that strengthen climate resilience, ensuring a reliable power supply amid climate disruptions while enabling a smooth transition away from fossil fuels.** Investments in centralized round-the-clock (RTC) renewable energy solutions can help mitigate grid disruptions while maintaining supply stability. Expanding decarbonization technologies in industries, such as green hydrogen and carbon capture, can reduce exposure to fossil fuel price volatility while ensuring compliance with evolving international trade and climate policies. Additionally, targeted clean energy investments in agriculture and transportation—such as decentralized solar irrigation, biofuels, and EV infrastructure—can enhance sectoral energy security while aligning with India's climate goals. Furthermore, to ensure a just transition, IGFF interventions should support job creation in emerging clean energy sectors, helping offset economic disruptions caused by coal dependency. A structured, well-financed clean energy transition will not only mitigate physical and transition risks but also drive long-term economic resilience while ensuring that the shift to clean energy.

1.4 India's commitment to a clean energy transition

18. **Recognizing this challenge, India is making demonstrated progress in its clean energy transition efforts, guided by its Paris commitments, Nationally Determined Contributions (NDCs) and net-zero target for 2070, with two of its NDC targets already nearing achievement.** Under its updated NDC, India has committed to reducing emissions intensity by 45% by 2030 (compared to 2005 levels) and ensuring 50% of cumulative installed electricity capacity comes from non-fossil sources. Additionally, the country has revised its renewable

[19] Afonso and Chaudhary, "In an increasingly water-scarce India, life's changing for steelmakers, and how", in Economic Times, 2019.
[20] source-contribution-and-congestion-impacts.pdf
[21] India's Carbon Border Adjustment Mechanism (CBAM) Challenge: Strategic Response and Policy Options - CSEP

energy target from 175 GW by 2022 to 500 GW by 2030. These commitments, along with India's Long-term Low Carbon Development Strategy, submitted to the UNFCCC in 2022, form the foundation of its decarbonization pathway.[22] As of October 31, 2024, 46.52% of India's total cumulative power capacity (211.39 GW) comes from non-fossil fuel-based sources (Table 3), bringing it close to meeting its 2030 NDC target of 50% cumulative installed electricity capacity from non-fossil sources. Additionally, efforts to decouple economic growth from emissions have already led to a 36% reduction in emissions intensity of the country's GDP between 2005 and 2020, with 45% set as the 2030 target.[23] Beyond its NDC and net-zero commitments, India's climate action is underscored by two decades of national initiatives, including those aimed at accelerating its clean energy transition. The National Action Plan for Climate Change, launched in 2008, introduced eight missions, including those focused on solar energy expansion and energy efficiency, laying the foundation for its early success in the RE space. More recently, the National Green Hydrogen Mission (2023) aims to scale up green hydrogen production, establish India as a global export hub, and integrate it as a clean energy alternative across industries. (For a detailed overview of India's commitments, targets, and key initiatives supporting the clean energy transition, please refer to Appendix 2)

Table 3. Sector-wise details of the installed capacity from non-fossil fuel-based energy sources, as of October 2024

Sector	Installed Capacity (GW)	Under Implementation (GW)	Tendered (GW)	Total Installed/Pipeline (GW)
Solar Power	92.12	103.06	56.59	251.77
Wind Power	47.72	23.53	1.1	72.35
Bio Energy (Including Biomass power/ Cogeneration and Waste to Energy)	11.33	-	-	11.33
Small Hydro	5.08	0.46		5.54
Hybrid/Round the Clock (RTC)/Peaking Power/Thermal + RE Bundling	-	-	32	32
Sub-Total	156.25	127.05	89.69	372.99
Large Hydro	46.97	20.05		67.02
Total	203.22	147.1	89.69	440.01
Nuclear Power	8.18	7.3	7	22.48
Total Non-Fossil Fuel	211.4	154.4	96.69	462.49

Data source: MNRE records, 2024

19. **Despite significant progress, India remains highly dependent on fossil fuels, with over 75% of its electricity generation still coming from coal, oil, and gas.** Meeting its clean energy commitments will require substantial support to accelerate the development and deployment of key technologies that can reduce this dependence while ensuring long-term energy security. Scaling up battery storage, RTC renewables, green

[22] India LT-LEDS
[23] India. Biennial update report (BUR). BUR 4. | UNFCCC

hydrogen for industrial use will be essential to stabilizing the grid, decarbonizing hard-to-abate sectors, and reducing reliance on fossil-based energy sources (further elaborated in Chapter 2). Without timely intervention, India risks falling short of its targets, leading to higher emissions and deepening carbon lock-in of its economy. Additionally, industries that fail to transition could face rising operational costs and competitiveness challenges, particularly as global trade policies such CBAM are increasingly adopted by other regions, imposing stricter regulations on high-emission exports. Hence, ensuring a well-supported clean energy transition is not only critical for meeting India's climate goals but also for maintaining economic resilience, avoiding stranded assets, and securing a competitive position in the global low-carbon economy.

1.5 Conclusion

20. **Given their dominance in India's energy consumption and emissions, decarbonizing the energy, industry, transportation, and agriculture sectors offers the greatest opportunity to accelerate the clean energy transition while ensuring long-term energy security and socio-economic growth.** These sectors are central to reducing fossil fuel dependence while simultaneously promoting income generation, improving quality of life, and supporting economic resilience. Without targeted interventions, continued reliance on coal, oil, and gas in these high-emitting sectors risks deepening inefficiencies, increasing emissions, and delaying India's net-zero ambitions, particularly as global trade and finance policies increasingly favor low-carbon economies. By focusing on these priority sectors, IGFF can help steer India's clean energy transition toward a more stable and sustainable trajectory, ensuring that investments not only drive emissions reductions but also strengthen economic competitiveness and long-term energy security.

2. India’s clean energy transition – current efforts, gaps, and needs

21. **This chapter provides an assessment of India’s clean energy transition, examining its progress, investment needs, and existing gaps across both technology and financing dimensions.** It begins by evaluating deployment trends for clean energy technologies against its targets, identifying policy and implementation challenges that continue to stagnate progress. Beyond RE capacity additions, the discussion expands to sector-wide decarbonization needs, particularly in industry, transportation, and agriculture, which require targeted interventions to align with India’s clean energy goals. The chapter also analyses India’s clean energy financing landscape, assessing where current investments come from, the key sources and instruments used, and how capital is allocated across sectors and technologies. By doing so, it establishes the rationale for IGFF’s role, setting the foundation for its priority technologies and financial instruments that will be deployed to accelerate India’s clean energy ambitions.

2.1 Current deployment rates against targets

22. **India ranks among the global leaders in renewable energy deployment, with solar and wind capacity expanding rapidly in recent years.** In 2024, India recorded its highest-ever annual capacity additions, reaching 34.7 GW—surpassing the previous 2015 record by 3.5 GW. Unlike a decade ago, when capacity additions were dominated by coal, the 2024 expansion was led by renewables (Figure 5). Solar accounted for 71% of total new capacity, with utility-scale solar comprising 75% of all solar installations. Wind energy additions reached 3.4 GW—one-third higher than the past decade’s annual average. However, hydropower and bioenergy additions remained limited at just 0.7 GW, representing less than 2% of total renewable capacity growth.[24] These capacity gains are being accompanied by major grid infrastructure expansions, improving connectivity to remote regions and bolstering transmission reliability.[25] Additionally, government policies and incentives—including the Production Linked Incentive (PLI) scheme for solar, battery, and electrolyzer manufacturing, waivers on inter-state transmission charges for renewables, Viability Gap Funding for solar and offshore wind, Renewable Purchase Obligations (RPOs), and the Uniform Renewable Energy Tariff (URET)—have played a pivotal role in strengthening India’s clean energy ecosystem. Amendments to the Energy Conservation Act (2001) now mandate minimum non-fossil energy consumption targets for industries, reinforcing decarbonization across the economy.

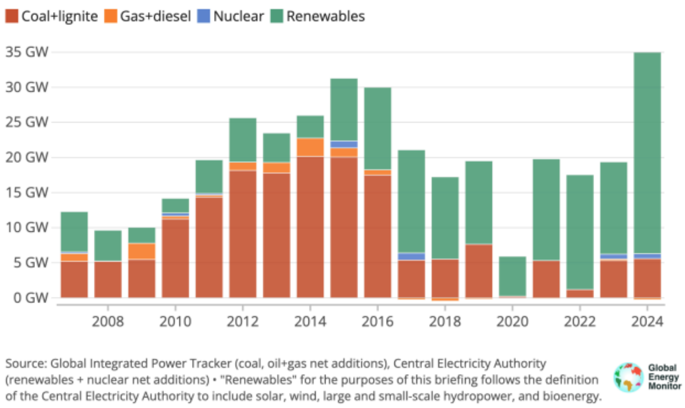

Figure 5. Annual net additions of power capacity in India (in GW), 2008-2024

[24] [Despite a record year, India needs to double renewables deployment by 2030 to meet energy targets - Global Energy Monitor]
[25] https://www.teriin.org/sites/default/files/files/Roadmap-to-India-2030-Decarbonization-Target.pdf

23. **Despite these achievements, India needs to accelerate its renewable energy deployment rate, requiring a twofold increase to reach its 500 GW installed capacity target by 2030.**[26] Historically, renewable energy capacity has grown at over 9% annually, far exceeding the non-renewable energy sector's growth of less than 3% since 2016-17 (Figure 6). In 2024, renewable installed capacity surged by 15.84% to 209.44 GW, demonstrating strong momentum. However, maintaining this pace consistently is crucial. Utility-scale solar and hydropower projects in pre-construction and construction phases are expected to surpass operating coal capacity within the next two years, with utility-scale solar alone comprising nearly half of all renewables in development. Still, renewables contributed only one-fifth of India's total power generation increase in 2024, while fossil fuels accounted for over two-thirds. Coal continues to meet 75% of electricity demand, with thermal plant utilization rates reaching a decade-high of 70%, compared to wind and solar generations' 17–22% average utilization rate. Meeting the 500 GW non-fossil fuel capacity target by 2030 will require India to sustain at least 15% year-on-year renewable growth—a rate achieved in 2024 but not consistently met in previous years. At current deployment rates, India's renewables capacity will grow to 378 GW by 2030—leaving a 100 GW shortfall. Closing this gap will require sustained increases in annual capacity additions, averaging 60% higher than 2024 levels, alongside continued policy support and investment in grid integration to accelerate the transition away from fossil fuels.

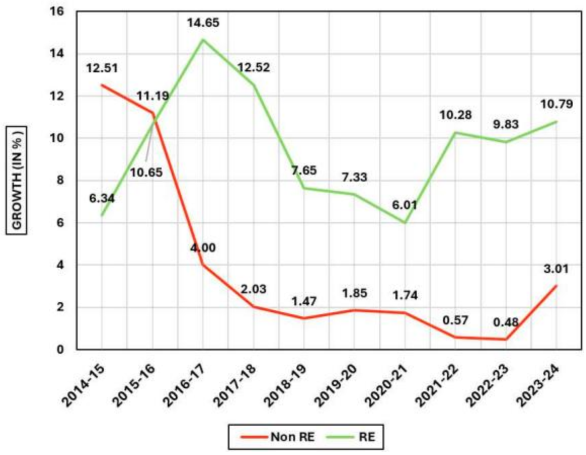

Figure 6. Comparison of year-on-year growth % for RE and non-RE sources in India, 2014-2024

Data source: MNRE, 2024.

24. **Even though India aims to accelerate RE capacity expansion, several structural and technical challenges must be addressed to enable this growth and ensure a stable, equitable, and scalable clean energy transition.** These include geographical disparities in renewable energy potential, intermittency and storage constraints, grid integration, and socio-economic barriers to energy access.

- **One of the biggest technical barriers to renewable expansion is the intermittent nature of solar and wind power, which makes round-the-clock energy supply challenging.**[27] Solar generation drops at night, and wind power fluctuates throughout the day, leading to energy deficits during peak demand periods if the grids were to entirely rely on variable renewable energy sources. Currently, coal plants compensate for these gaps, which can partially explain their dominance in power generation despite

[26] GEM India brief February 2025
[27] https://www.nature.com/articles/s41467-023-41971-7

growing renewable installations. The IEA estimates that India will require 27 GW of battery storage by 2030 to stabilize renewable energy supply and manage peak demand fluctuations.[28] However, storage deployment remains insufficient, with high costs and limited infrastructure slowing large-scale adoption. While pumped hydro storage projects and emerging solutions like compressed air energy storage offer potential alternatives, long permitting timelines and land acquisition delays continue to constrain their expansion.[29] Addressing this requires scaling investments in battery storage, improving regulatory frameworks, and incentivizing hybrid renewable-storage projects to ensure greater grid flexibility and supply reliability.

- **India's renewable energy resources are unevenly distributed, creating significant regional imbalances in capacity deployment.** States like Gujarat, Tamil Nadu, Karnataka, Maharashtra, Rajasthan, and Andhra Pradesh have harnessed substantial wind and solar capacities due to favorable climatic conditions. In 2024, Rajasthan, Gujarat, and Tamil Nadu alone contributed to 70.76% of India's total solar installations. Similarly, Gujarat, Tamil Nadu, Karnataka, Maharashtra, Rajasthan, and Andhra Pradesh collectively accounted for 93.37% of the country's wind capacity.[30] Conversely, regions such as the northeastern states and parts of central India exhibit lower renewable energy potential, as reflected in the negligible contributions from states like Meghalaya, Nagaland, and Odisha in terms of capacity addition.[31] According to the MNRE data on total installed new renewables capacity (includes solar, wind, and bioenergy) as of December 31, 2024, the Northeastern states contributed just 0.21% of the national total, while the Eastern states accounted for 1.43%. In comparison, the North, West, and South regions held significantly larger shares at 26.7%, 32.66%, and 38.92%, respectively (Figure 7).[32] Beyond natural resource availability, topographical and climatic risks in certain regions exacerbate energy insecurity. The northeastern states frequently experience power disruptions due to earthquakes, floods, and landslides, damaging transmission lines and increasing operational and maintenance costs.[33] Even when grid infrastructure is present, high transmission and maintenance costs drive up electricity prices, making energy access less affordable in these regions. To bridge this gap, hybrid solutions integrating solar, wind, and battery storage, along with decentralized renewable energy applications, are necessary for ensuring a more balanced energy supply across all regions.[34]

[28] Verma, "India's energy transition: Challenges and opportunities for a sustainable future", in Times of India, 2023.
[29] Pathways to net zero emissions for the Indian power sector (Das et al., 2023)
[30] Factsheet Details:
[31] NIWE Resource Portal - hybrid Map; 202501081447570936.pdf
[32] 202501081447570936.pdf; Regional classifications used in this analysis are as follows—South: Andhra Pradesh, Telangana, Karnataka, Kerala, Tamil Nadu, Puducherry, and Lakshadweep; West: Gujarat.
[33] Issues and Challenges in Working Towards a Disaster Resilient Northeast India
[34] ceew-study-on-powering-livelihoods-with-distributed-renewable-energy-systems.pdf

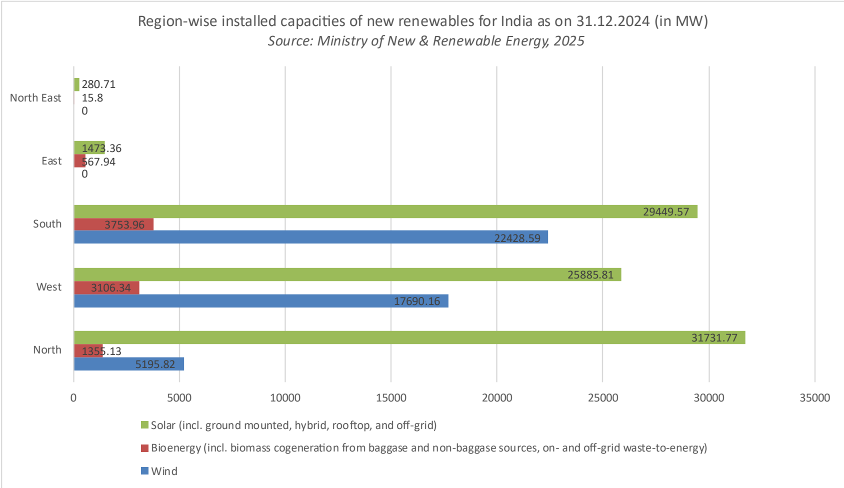

Figure 7. Region-wise installed capacities of new renewables for India, 2024

- **The rapid expansion of solar and wind capacity has placed significant stress on India's existing grid infrastructure, which struggles to accommodate the variability of renewable energy generation.** Unlike coal plants, which provide steady baseline power, renewables fluctuate based on weather conditions and time of day, creating grid frequency imbalances and supply-demand mismatches.[35] According to the CEA, inconsistent renewable energy injection into the grid has led to frequent frequency deviations, complicating grid stability. Transmission constraints also hinder the efficient flow of renewable power across states.[36] The concentration of solar and wind projects in western and southern India, while major demand centers lie in the north and east, exacerbates regional power deficits. The Green Energy Corridor (GEC) initiative, which aims to improve transmission infrastructure for renewables, has made progress but remains inadequate in fully addressing interstate power evacuation needs. Grid congestion continues to limit renewable energy utilization, delaying integration into the national power supply. Expanding transmission networks and deploying advanced grid management technologies, such as real-time monitoring systems and smart grids, will be crucial in accommodating higher renewable penetration.

- **Despite the expansion of grid connectivity, many rural and low-income communities still face unreliable and unaffordable electricity supply.** Despite various policy initiatives aimed at enhancing electricity supply, many rural regions continue to experience unreliable power, characterized by frequent outages and voltage fluctuations. States such as Uttar Pradesh, Bihar, Jharkhand, Odisha, West Bengal, and Madhya Pradesh have some of the highest frequencies and durations of power outages, which severely hampers economic development and perpetuates energy poverty among marginalized communities. According to a survey conducted on energy access in these "energy poor" states, while domestic electricity connections in rural areas have increased, the quality of supply remains inadequate, with many households still relying on traditional fuels due to poor availability and high costs of cleaner alternatives like LPG.[37] The uneven distribution of subsidies and resources has led to a scenario where wealthier areas benefit disproportionately from electrification efforts. For instance, successful states like Punjab have implemented equitable subsidy distribution models that cater to all income groups, while poorly performing states have primarily focused on grid connections for middle-

[35] The Integration of Non-dispatchable Renewables (Baroni, 2019)
[36] Delay in transmission infra bigger challenge for RE expansion than land availability: SECI MD
[37] ceew-research-energy-poverty-measuring-energy-access-india.pdf

and high-income areas.[38] This inequity has resulted in significant portions of the rural population remaining disconnected from reliable energy sources.

Clean energy transitions as engines for job creation. In 2023, India's renewable energy sector employed approximately 1.02 million people, reflecting its growing role in the global clean energy workforce, which expanded to 16.2 million, up from 13.7 million in 2022, according to IRENA's 2024 Annual Review. Solar PV remained the largest employer, supporting 318,600 jobs, with 238,000 in grid-connected solar—an 18% increase from 2022—and 80,000 in off-grid systems. The wind sector employed 52,200 people, with nearly 40% in operations and maintenance and 35% in construction and installation. Other renewable energy sectors also contributed significantly, with liquid biofuels supporting 35,000 jobs, solid biomass 58,000 jobs, and biogas 85,000 jobs, while the solar heating and cooling sector employed 17,000 people. This broad-based job growth underscores the renewable energy sector's increasing contribution to India's employment landscape, highlighting its role in both economic expansion and the clean energy transition.

Source: Ministry of New and Renewable Energy, 2024.

25. **Despite ambitious targets and policy measures, persistent implementation challenges continue to slow India's progress toward its clean energy goals, preventing the scale and speed required to meet its ambitions.** The Ministry of New and Renewable Energy (MNRE) has outlined a plan to conduct annual bids of 50 GW of new renewable capacity until 2027-28, with implementation overseen by agencies such as the Renewable Energy Implementation Agencies (REIAs), National Thermal Power Corporation (NTPC), and the Solar Energy Corporation of India (SECI).[39] These entities bid for projects, select developers, and sell power to distribution companies (DISCOMs). However, as of 2024, annual additions stand at just 28.64 GW, more than double the 13.05 GW added in 2023 but still far below the 50 GW target needed to align with India's NDCs, as established above.[40] This shortfall persists despite key policy incentives, including exemptions from inter-state transmission charges for projects commissioned by June 30, 2025, and Renewable Purchase Obligations (RPOs) and Renewable Consumption Obligations (RCOs) extended until 2029-30, which mandate that all consumers procure a defined share of their electricity from renewables, with penalties for non-compliance.[41] The following section examines key implementation challenges that continue to hinder India's renewable energy expansion despite these policy measures.

- **Delays in translating Power Supply Agreements (PSAs) into Power Purchase Agreements (PPAs) slow project execution, creating financial uncertainty and limiting transparency in renewable energy procurement.** SECI, India's primary renewable energy trader, mitigates risks by signing 25-year PSAs with DISCOMs before finalizing PPAs with developers, shielding them from DISCOM payment defaults.[42] However, SECI remains liable under PPAs even when DISCOMs delay payments, straining its financial sustainability.[43] As of June 2024, 34.5 GW of projects remain uncommissioned, including 12.5 GW of solar projects facing delays linked to domestic manufacturing bottlenecks. The lack of publicly available PSA-PPA linkages further hampers transparency, making it difficult to assess project viability.[44] To prevent further delays, SECI and other energy traders require liquidity support to bridge financing gaps when DISCOMs delay payments. Short-term working capital credit lines or guarantee-backed bridge loans—modeled after the Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE)—could offer

[38] Socio-Economic Sustainability of Rural Energy Access in India
[39] Government declares plan to add 50 GW of renewable energy capacity annually for next 5 years to achieve the target of 500 GW by 2030
[40] India's Renewable Energy Surge: MNRE Reports Record 209.44 GW Capacity in 2024, Doubling Year-on-Year Growth - SolarQuarter
[41] Press Release: Press Information Bureau
[42] Breaking Down the Gap in DisCom Finances: Explaining the Causes of Missing Money - CSEP
[43] Seci.indd
[44] India's Ambitious 500 GW Clean Energy Target by 2030: A Deep Dive

solutions. Additionally, making PSA-PPA linkages public would improve accountability and boost investor confidence.

- **Despite falling solar tariffs, weak offtake demand continues to leave renewable capacity stranded.** As of December 2024, 9.2 GW of renewable projects lack buyers, with NTPC Green's unsold pipeline reaching 11 GW and Adani Green Energy holding 1.799 GW despite competitive tariffs of INR 2.42 per kWh.[45] DISCOMs' reluctance to sign PSAs at higher long-term tariffs (20–25 years) and their continued reliance on legacy coal-based PPAs, which guarantee nighttime supply but impose fixed capacity payments, further hinder procurement. 22 out of 28 states failed to meet their 2023 solar RPO targets, despite tariffs dropping from INR 6 per kWh in 2015 to INR 2.5 per kWh in 2023.[46] To address this, credit guarantees or payment security mechanisms could ensure developers receive payments even if DISCOMs delay or default. The Atmanirbhar Bharat relief package (2020) provided liquidity support of INR 90,000 crore to power DISCOMs via the Power Finance Corporation and Rural Electrification Corporation, with provisions for state-guaranteed loans to discharge liabilities to power generators. Expanding such models, blended finance solutions combining concessional capital with commercial funding could lower the effective tariff burden on DISCOMs, making renewables more financially viable and ensuring procurement stability.

- **Given the intermittency of new renewables, it is now proposed that the country should move towards round-the-clock (RTC) projects; yet the costs remain prohibitively high, slowing down their uptake.** The Economic Survey 2023-24 notes that the Union Ministry of Power has issued tariff guidelines for grid-connected renewable projects classified as "firm and dispatchable renewable energy" (FDRE). While inter-state transmission-connected solar PV projects have been bid at INR 2.6–2.74 per kWh, RTC project costs can rise to INR 6 per kWh. However, there is limited information on their commissioning. For instance, SECI's hybrid RTC project, with an effective PPA date of 2021, remains uncommissioned. Industry experts question whether DISCOMs, already under financial strain, will accept the higher costs of RTC power, while the other side of the argument is that RTC tariffs must remain competitive with fossil fuel-based power, which benefits from round-the-clock availability.[47] To bridge this gap, financing models need to incentivize hybrid solutions (e.g., solar+ wind+ storage) by lowering upfront costs through long-tenure, low-interest loans. The Renewable Energy Development Agency (IREDA), through its concessional financing for storage-linked renewables, offers a model that could be expanded for RTC deployment. Additionally, innovative solutions such as time-of-day pricing incentives—where financial support helps offset higher RTC tariffs during peak demand hours—could make RTC energy more competitive.

- **In the agriculture sector, high upfront costs, limited access to affordable financing, and policy constraints are hindering the adoption of solar water pumps under schemes like PM-KUSUM, keeping it from achieving its targets.** The Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan (PM-KUSUM) scheme, launched in 2019, aims to integrate renewable energy into agriculture by subsidizing solar water pumps and enabling farmers to generate income from solar power plants on barren land. However, implementation challenges persist, particularly under Component B, which targets 1.75 million standalone solar pumps. While about 0.5 million pumps have been installed—primarily in Haryana, Maharashtra, and Rajasthan—progress has been slow due to high upfront costs and limited access to affordable financing. Despite 30–50% subsidies, farmers must still finance a significant portion of the cost, with a 3 HP solar pump averaging INR 1.7 lakh, which remains unaffordable for small and marginal farmers.[48] Smallholder farmers struggle to access low-interest loans to meet their equity financing portion, with formal financing often requiring collateral and interest rates of 12–14%, pushing many towards high-cost informal credit, adding on to their existing debt and poverty traps if they wish

[45] India's Ambitious 500 GW Clean Energy Target by 2030: A Deep Dive
[46] Policy Paper_Energy_12022024_V4.pdf; 20th_EPS_Report_Final_16.11.2022.pdf
[47] India's Ambitious 500 GW Clean Energy Target by 2030: A Deep Dive
[48] Under-utilisation of standalone solar pumps remains a challenge

to adopt the technology.[49] Additionally, strict procurement policies under the Approved List of Models and Manufacturers (ALMM) mandate domestically produced solar modules, which are costlier than imported alternatives, further raising prices.[50] The availability of free or highly subsidized electricity in some states has also reduced demand for solar pumps. These barriers continue to hinder widespread adoption, leaving PM-KUSUM far from meeting its targets.[51] Targeted financing solutions, such as concessional lending programs with lower ticket-size borrowing options, including bundled loan structures, can enhance affordability for farmers. Additionally, streamlining procurement policies can help reduce costs and accelerate adoption of clean energy technologies in agriculture.

- **Finally, ensuring energy security for rural and low-income households requires a decentralized energy delivery model that large-scale renewables are not able to meet; yet the latter dominates the current policy vision.** The existing grid-based system, designed for fossil fuels, struggles to meet the needs of millions still living in energy poverty. Even as grid expansion continues, many households remain without reliable electricity due to affordability constraints, financially strained DISCOMs, and market failures in serving cash-strapped consumers.[52] Beyond electricity access, clean cooking remains a critical challenge. An estimated 66% of Indians still rely on biomass for cooking, exposing women to harmful emissions. By 2030, the International Energy Agency predicts 43% of the developing world will still depend on biomass, highlighting the slow pace of transition.[53] Additionally, land constraints pose another barrier to renewables expansion as mentioned above. Optimizing available land through agrivoltaics or rooftop solar can help integrate distributed generation, lowering costs and making energy access more inclusive. Uptake of decentralized renewable energy as off-grid solutions have mainly been in the form of street lighting and select on-farm applications for agriculture, such as solar pumps and solar feeders. However, DRE has broader potential, particularly for powering income-generating activities in rural areas, including for powering the dairy sector, rice and millet milling and processing, aquaculture farming etc.[54] Unlocking its full benefits will require policies and financing that prioritize clean energy for livelihoods, ensuring a just and inclusive energy transition.[55] The latter can take the form of Pay-as-you-go (PAYG) solar models, successfully deployed in Kenya and Bangladesh, that could help scale adoption in India by allowing households to make small, flexible payments instead of large upfront investments. Additionally, aggregating financing for small-scale DRE projects through regional banks could unlock capital for micro-enterprises looking to install renewable-powered livelihood solutions, such as solar-powered dairy processing or cold storage for agricultural produce.

2.2 Key technology needs

26. **While scaling renewable energy capacity, strengthening grid infrastructure, expanding storage and decentralized solutions are critical to India's clean energy transition, they alone will not be enough to achieve the levels of deep decarbonization needed to become net-zero by 2070.** The clean energy shift must extend beyond the power sector and promote decarbonization efforts in energy-intensive industries, transportation, and agriculture, which collectively drive a significant share of India's energy demand and emissions, as detailed in Chapter 1. Achieving this requires scaling up clean technologies such as low-carbon cement and steel production, green hydrogen for industrial applications, electrification of freight and public transport, and decentralized renewable energy (DRE) for rural livelihoods. In agriculture, this means replacing diesel-powered irrigation pumps with off-grid solar solutions, expanding bioenergy alternatives like compressed biogas (CBG), and integrating energy-efficient cold storage for post-harvest preservation. These solutions are essential for

[49] Indias-Vast-Potential-in-Solar-Powered-Irrigation-.pdf
[50] Updated (06.01.2025) List-I under ALMM order for Solar PV Modules | MINISTRY OF NEW AND RENEWABLE ENERGY | India
[51] Implementation Challenges of the PM-Kusum Scheme
[52] 100% rural electrification is not enough - The Hindu BusinessLine
[53] SDG7: Data and Projections – Analysis - IEA
[54] 2022122711.pdf
[55] Financing Decentralized Renewable Energy (DRE) Based Sustainable Livelihoods - Selco Foundation

reducing fossil fuel dependence, increasing energy efficiency, and ensuring an inclusive energy transition across all economic sectors.

27. **Recognizing this, India has launched several missions, schemes, and initiatives to drive decarbonization across these sectors, complementing its renewable energy expansion efforts.** The Perform, Achieve, and Trade (PAT) Scheme, under the National Mission on Enhanced Energy Efficiency (NMEEE), incentivizes industrial efficiency improvements, while the Faster Adoption and Manufacturing of Electric Vehicles (FAME) Scheme promotes EV adoption and charging infrastructure expansion to reduce the transport sector's dependence on fossil fuels. Further, to lower EV battery costs—currently accounting for ~40% of total vehicle costs—the government has introduced a Battery Swapping Policy and a Production Linked Incentive (PLI) Scheme on Advanced Chemistry Cells (ACC).[56] Meanwhile, the National Green Hydrogen Mission is designed to scale up green hydrogen production for steel and chemical industries, positioning India as a global leader in clean industrial fuels. In the agriculture sector, the PM-KUSUM scheme aims to transition farmers from diesel-powered irrigation to solar pumps, reducing costs and emissions while improving energy access. However, many of India's decarbonization policies and the technologies they aim to promote are still in early implementation stages and require sustained national and international support to be effectively realized (For a comprehensive overview of sectoral policies in energy, industry, transportation, and agriculture, along with their achievements to date against targets, please refer to Appendix 2.)

28. **Table 4 below highlights the critical technologies needed to accelerate India's clean energy transition and deep decarbonization, built on the country's stated priorities and needs.**[57] The technologies highlighted here align with IGFF's focus areas—energy, industry, transportation, and agriculture—and form the foundation for its priority technologies and applications.

Table 4. India's technology needs for advancing its clean energy transition

S.No.	Sector (Sub-sector)	Description	Type of Technology/ Application	Expected Use, Impact, and Estimated Results	Contribution to the Clean Energy Transition
1	Energy (Solar)	Development of ultra-efficient photovoltaic cells, hybrid PV-Thermal systems, and space-saving PV applications (e.g., agri-PV, rooftop, and floating solar).	Advanced Photovoltaics	Increased solar efficiency, reduced land footprint, and integration into diverse applications such as buildings and agricultural landscapes.	Expands solar energy deployment in space-constrained areas, reducing land conflicts and improving energy accessibility.
2	Energy (Wind Energy)	Deployment of floating wind turbines for offshore energy production.	Offshore Wind Turbines	Unlocks offshore wind potential, providing a stable power source without competing for land.	Enhances wind power generation capacity, diversifies energy sources, and improves grid stability.

[56] Your EV is 40% Chinese, and will remain so if this jigsaw is not solved - The Economic Times
[57] India. Biennial update report (BUR). BUR 4. | UNFCCC

3	Energy (Advanced Bioenergy)	Conversion of biomass into compressed biogas (CBG) for clean energy applications.	Compressed Biogas (CBG)	Reduces methane emissions, provides a renewable fuel alternative, and supports circular waste management.	Replaces fossil fuels in industrial and agricultural applications, improving waste-to-energy efficiency.
4	Energy (Energy Storage Systems)	Advanced battery chemistries, solar-thermal energy storage, hydrogen storage, and flywheel energy storage technologies.	Battery and Energy Storage Systems	Stabilizes power supply, ensures round-the-clock renewable energy availability, and supports grid reliability.	Enables large-scale renewable energy integration, addressing intermittency issues.
5	Industry (Cement and Steel)	Adoption of low-carbon production technologies and alternative materials in heavy industries.	Low-carbon Industrial Technologies	Reduces emissions from high-temperature industrial processes, increases efficiency, and promotes cleaner production.	Essential for decarbonizing hard-to-abate sectors like steel and cement.
6	Industry (Cement, Iron, and Steel)	Deployment of Carbon Capture, Utilization, and Storage (CCUS) technologies.	CCUS Technologies	Captures and stores CO_2 emissions from industrial processes, reducing carbon intensity.	Provides an immediate pathway to decarbonize industries where electrification is not viable.
7	Industry (Energy Efficiency Technologies)	Integration of inert anode technology (non-ferrous sector), solar-powered mechanical vapor recompression (MVR), and energy-efficient cement production (LC3).	Industrial Energy Efficiency Solutions	Enhances energy efficiency, reduces fuel consumption, and lowers emissions across industrial operations.	Decreases fossil fuel reliance in high-energy-consuming industries.
8	Transport (EVs)	Scaling up electric vehicle adoption and charging infrastructure.	Electrification Technology	Cuts transport-related emissions, improves air quality, and reduces reliance on imported oil.	Enables a cleaner mobility transition, supporting urban sustainability and emissions reduction.

9	Transport (Hydrogen Fuel Cells)	Development of hydrogen as a clean fuel alternative, especially for freight and public transport.	Hydrogen Fuel Cells	Provides a zero-emission, high-energy-density fuel alternative for long-haul transport and heavy industries.	Decarbonizes transport sectors where battery electrification may not be feasible.
10	Agriculture (Precision Agriculture)	Deployment of climate-resilient agricultural technologies for optimized water, fertilizer, and pesticide use.	Precision Agriculture	Increases crop yields, reduces resource wastage, and improves resilience to climate change.	Reduces emissions from inefficient resource use while enhancing productivity.
11	Agriculture (Solar Feeders)	Installation of solar-powered feeders to supply reliable electricity to agricultural consumers.	Solar Feeders	Provides clean, affordable power to farms, reducing dependence on subsidized grid electricity.	Cuts reliance on coal-based power and improves rural energy sustainability.
12	Agriculture (Decentralized On- and Off-Farm Applications)	Deployment of solar-powered irrigation pumps, cold storage units, and other decentralized renewable energy solutions.	Decentralized Renewable Energy (DRE) for Agriculture	Enables clean energy for farming operations, reduces post-harvest losses, and improves rural electrification.	Reduces dependence on diesel generators, making agricultural energy use more sustainable.

2.3 Current finance landscape

29. **Scaling these priority technologies requires a strong investment environment, and India is rapidly emerging as one of the most cost-competitive and investment-friendly markets for clean energy.** Driven by declining technology costs, improving risk profiles, and strong policy support, India has consistently ranked among the top 10 emerging markets in the BNEF Climatescope assessment.[58] The declining cost of clean energy technologies, particularly solar and wind, continues to drive cost-effectiveness and scalability, further reducing risk profiles for investors. India boasts one of the world's lowest levelized costs of electricity (LCOE) for solar energy, ranging from USD 25–43 per MWh, significantly cheaper than in most other countries, with onshore wind similarly competitive at USD 32–51 per MWh (Figure 8).[59] Between 2014 and 2022, solar tariffs fell by over 75% and wind tariffs by 55%, reinforcing long-term cost reduction trends. The risk profile of utility-scale renewable energy projects has also improved, with 90% of solar projects receiving investment-grade ratings in 2020, compared to none in 2012.[60] Meanwhile, advancements in solar PV efficiency, wind turbine design, green

[58] Climatescope 2023 (global-climatescope.org)
[59] India Renewables Financing (bbhub.io)
[60] Climate Policy Initiative, "Landscape of Green Finance in India 2024", 2024.

hydrogen, and energy storage technologies, coupled with India's commitment to investing over USD 35 billion annually in these sectors, including for domestic manufacturing, are strengthening the viability of clean energy investments and attracting greater interest from domestic and international financiers.[61] However, despite these commitments, the pathway to mobilizing this capital at scale remains uncertain, particularly as business models for emerging technologies like green hydrogen and long-duration storage are still unproven, regulatory frameworks remain nascent, and revenue certainty for investors is limited.[62]

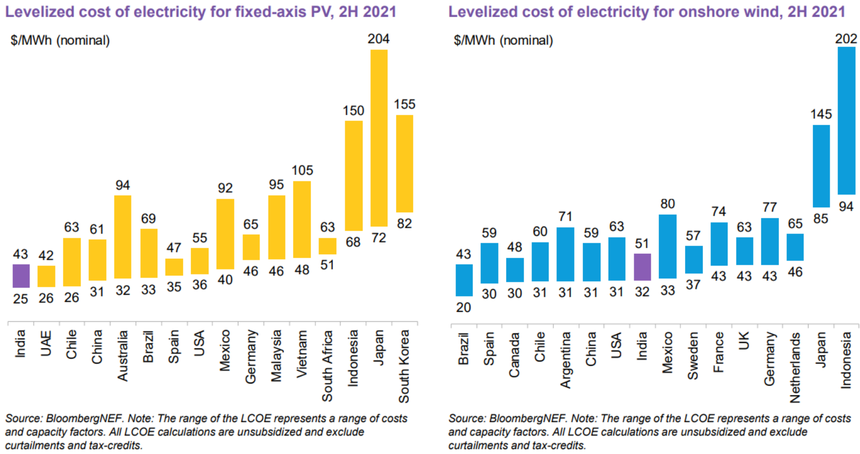

Figure 8. Levelized cost of electricity for solar PV and onshore wind, 2021

30. **Despite the above achievements, India's clean energy transition requires annual financing to more than double from current levels to meet its NDC targets.** In 2021/22, green finance flows reached USD 50 billion annually, reflecting a 20% increase from 2019/20, despite global economic disruptions.[63] However, this falls significantly short of the USD 170 billion required annually to meet India's 2030 NDC targets and achieve net-zero by 2070. Current financing levels cover only 30% of the required investment, signaling a significant gap in capital deployment (Figure 9). The cost of inaction is even greater—if emissions are not substantially reduced, economic losses from climate change could reach USD 35 trillion by 2070, or 12.5% of India's GDP; this is without accounting for the indirect costs of biodiversity loss, social inequalities, and other compounding factors.

[61] How India is emerging as an advanced energy superpower | World Economic Forum
[62] Accelerating the deployment of advanced energy solutions | World Economic Forum
[63] Climate Policy Initiative, "Landscape of Green Finance in India 2024", 2024; This section on the current financing landscape is largely based on insights from this report, which analyses green finance flows in India for the financial years 2021 and 2022. The figures presented represent the average annual investment across these two years. For a detailed breakdown of sub-sectors covered in the study, readers are encouraged to refer to the original source.

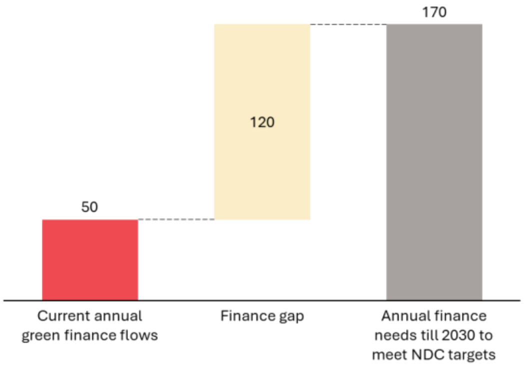

Figure 9. Current green finance gap for India based on 2021/22 flows

31. **Of the estimated USD 170 billion annual financing requirement, approximately USD 28 billion is needed solely for solar and wind installations to meet India's optimal energy mix for 2030.** Between 2020 and 2029, India requires USD 363 billion in investments to build new power projects and battery storage to align with the Central Electricity Authority's optimal capacity mix for 2030, according to BNEF estimates.[64] Within this, USD 241 billion is needed for the construction of solar and wind power plants, while USD 26 billion is required for battery storage projects. However, in 2020 and 2021, new-build solar and wind projects secured only USD 17.4 billion in asset financing, significantly lower than the USD 27.9 billion annual requirement to stay on track. Beyond power generation, an additional USD 175 billion is needed over the same period to upgrade and expand the transmission and distribution (T&D) grid, ensuring seamless integration of renewable energy into the system. Without timely investment in storage and grid modernization, integrating high shares of renewables could increase system inefficiencies, lead to curtailments, and heighten grid reliability risks.

32. **While utility-scale solar and wind will continue to be central to India's transition, the current financing landscape remains heavily concentrated in these large projects, leaving other critical areas underfunded.** In 2021/22, solar PV alone accounted for 48% of all tracked clean energy investments, while onshore wind and hydro received 17% and 16%, respectively, and biofuels just 1% (Figure 10). In clean transportation, which accounted for 18% of total low-carbon investments, nearly 80% was allocated to mass rapid transit systems (MRTS), with only 12% directed toward electric vehicles (EVs), despite their growing role in decarbonization. Additionally, funding for research and development across all sectors remains negligible compared to project financing, despite its critical role in fostering innovation and scaling the next stage of clean energy technologies. Hence, to support a secure, reliable, and long-term clean energy transition, India must diversify its investment flows beyond large-scale power generation. Greater financing is needed for battery storage, hybrid/RTC renewables, green hydrogen, and biofuels, which are essential for improving grid stability, reducing dependence on fossil-fuel-based backup power, and decarbonizing hard-to-abate sectors. This shift in investment focus is also necessary to align with India's communicated technology needs, ensuring that capital flows effectively support the next phase of clean energy deployment while addressing sector-wide challenges.

[64] Optimal_mix_report_2029-30_FINAL.pdf (cea.nic.in)

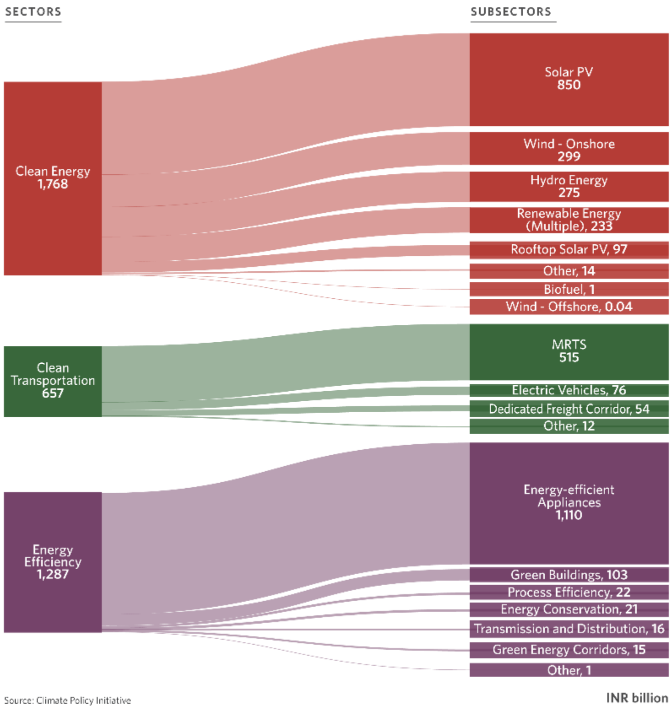

Figure 10. Green finance flows by sectors for fiscal years 2021/22 (INR bn)

33. **The current financing landscape is heavily reliant on domestic sources (83%) and debt financing (50%), creating additional challenges in sustainably mobilizing the capital required to meet India's clean energy targets.** Within domestic financing, private sector lending made up to 66% of the total flows, with commercial financial institutions contributed 39%, primarily directed toward industrial energy efficiency and utility-scale solar and wind projects. Within the public sector, government budgets—both central and state—accounted for 54% of domestic public finance, while public sector undertakings (PSUs) contributed 43%. Notably, 93% of their financing was allocated to clean energy, with 4/5th of it flowing to large-scale hydro and RE installation projects. Internationally, bilateral DFIs accounted for 68% of total public international flows (USD 2.1 billion), while multilateral DFIs contributed the remaining 32% (USD 1 billion), with nearly 65% of these flows directed toward clean transportation projects, particularly MRTS and the Dedicated Freight Corridor. Across all domestic and international debt financing, which constituted half of all tracked green finance flows, 64% was raised through direct balance sheet issuances, 24% through low-cost project debt, and 12% through project-level market-rate debt. On average, the cost of debt stood at 8.7% across new-build wind and solar projects for that year. Public sector undertakings remain the largest providers of low-cost financing, allocating 99% of their concessional project debt to clean energy, though most of it was concentrated in solar PV, onshore wind, and hydro. While international finance increased slightly from 15% in 2019/20 to 17% (USD 8.3 billion) in 2021/22, its contribution remains far below what is needed to meet India's clean energy investment requirements. Given the high capital costs of emerging technologies and infrastructure expansion, the limited availability of concessional international finance presents a major hurdle in scaling India's energy transition at the required pace. This challenge is further compounded by India's constrained fiscal capacity, making it difficult to rely on market-rate borrowing to meet the magnitude of investments required.

34. **To address these gaps, India is increasingly leveraging innovative financing mechanisms, such as green bonds, blended finance structures, and credit enhancement tools, to mobilize private capital and international investment.** India's green bond market—now the second largest among emerging Asian economies—raised USD 9.7 billion in 2021 alone, underscoring growing investor interest in climate-aligned

financial instruments. Additionally, results-based financing models, sovereign green bonds, and de-risking mechanisms like the Partial Risk Sharing Facility (PRSF) for energy efficiency are being deployed to increase private sector participation. However, while these tools have helped unlock capital for large-scale renewables and MRTS projects, they have not yet been deployed at scale to sufficiently address funding shortfalls in emerging technologies like RTC renewables, energy storage, green hydrogen, and decentralized energy solutions. Blended finance structures that integrate concessional funding with commercial capital will be essential to reducing investment risks and accelerating private sector participation in these underfunded segments.

35. **Ultimately, India must significantly expand both the scale and scope of clean energy financing to meet its ambitious decarbonization goals.** Rebalancing capital flows away from just large-scale utility solar and wind toward emerging technologies that ensure grid reliability, industrial decarbonization, and rural energy access will be critical. While domestic financial institutions, particularly PSUs, will continue playing a leading role in climate finance, international concessional capital must increase to fill financing gaps, particularly in high-risk, high-impact segments such as biofuels and battery storage. Strengthening multilateral finance partnerships, expanding risk-sharing mechanisms, and ensuring access to low-cost long-term debt will be key to unlocking the next phase of India's clean energy transition.

2.4 Barriers to scaling finance for emerging clean energy technologies

36. **Accessing affordable and high-impact capital from diverse sources to finance the next wave of clean energy technologies (ref. Section 2.2) remains a challenge due to their need for patient, long-term investment, the existing finance gap, and their limited focus within current funding structures.** These factors are slowing efforts to rapidly scale their development and deployment, restricting progress in emerging clean energy solutions. Key challenges include high capital costs and risk perceptions for emerging technologies, constraints in accessing long-term debt, macroeconomic headwinds such as currency fluctuations, and insufficient and delayed access to international climate funds. The following sections detail these barriers:

- **High capital costs and risk perception.** Advanced and emerging technologies such as Round-The-Clock (RTC) solar, green hydrogen, and stand-alone solar PVs to power decentralized RE applications demand substantial upfront capital investments, posing a significant barrier to scaling, especially in rural sectors and regions.[65] For instance, green hydrogen production costs currently range between USD 5–6 per kg, at least three times higher than conventional hydrogen, making it economically uncompetitive without targeted support.[66] The nascent stage of these technologies amplifies investor concerns, as they carry high perceived risks due to technological uncertainties, long payback periods, and the absence of a proven track record. These challenges are particularly acute for emerging solutions that lack large-scale demonstration or established market confidence.
- **High borrowing costs:** One of the primary financial risks for renewables is the elevated borrowing costs, heavily influenced by India's macroeconomic policies. Recent increases in the Reserve Bank of India's benchmark repo rate, response to inflation and post-Covid economic recovery, have led to a trajectory of rising bank loan rates and bond yields. Between May 2022 and February 2023, the central bank raised the repo rate by a total of 250 bps to 6.5%, up from the record low of 4% it had kept for two years. Foreign borrowing through green bonds is also affected by the prevailing high-interest rate environment in major economies like the UK, EU, and the US, making new issuances in emerging markets less competitive.[67]

[65] https://t20ind.org/wp-content/uploads/2023/07/T20_PB_TF4_418_FinanceToScaleDRE_ForUpload.pdf
[66] Making Green Hydrogen a Cost-Competitive Climate Solution (IRENA, 2021).
[67] Financing and Funding Trends (IEA, 2019)

- **Constraints in accessing long-term, low-cost debt financing:** The renewable energy sector faces significant challenges in securing reliable, patient, and affordable debt financing, critical for large-scale, capital-intensive projects. One of the reasons is the energy sector's stranded assets burden, which constrains the ability of financial institutions to extend long-tenure loans. The lack of long-tenure financing is exacerbated by structural challenges in India's green finance ecosystem. For instance, most green bonds issued in India have maturities of less than 10 years, which is insufficient to match the extended payback periods required by renewable energy projects. Additionally, regulatory frameworks and prudential sectoral exposure limits imposed by the Reserve Bank of India further restrict the flow of affordable, long-term debt to the sector.

- **Macroeconomic headwinds:** India's clean energy sector faces additional challenges from macroeconomic volatility, such as currency fluctuations and sovereign credit rating pressures, which impact international financing flows. Depreciation of the Indian rupee raises the cost of importing clean energy equipment, such as solar PV modules, battery technologies, and wind turbines, while also increasing the burden of servicing dollar-denominated debt. These challenges are compounded by uncertainties around India's sovereign credit rating, which is currently rated Baa3 by Moody's.[68] Any potential downgrade could reduce investor confidence and limit global fund exposure, further constraining access to affordable international finance.

- **Inadequate and inaccessible international climate funds:** The Green Climate Fund (GCF), with a portfolio of approximately USD 16 billion, is insufficient to meet the extensive climate financing needs of developing countries, creating intense competition for limited resources.[69] Access to these funds is further constrained by stringent eligibility criteria and complex application processes, which often overwhelm the institutional capacity of recipient nations. This mismatch between funding availability and urgency hinders timely and adequate support for critical climate projects, particularly in countries like India.

37. **Innovative finance structure, including blended finance – which combine public and private capital – and risk guarantee facilities can help overcome systemic constraints by lowering investment risks and improving access to affordable finance for clean energy projects.** India's financial sector faces significant constraints in extending long-term, low-cost debt, partly due to high levels of non-performing assets (NPAs) and regulatory exposure limits that restrict lending to high-risk sectors. By using concessional capital to absorb a portion of project risks, blended finance mechanisms enhance the creditworthiness of clean energy investments, making them more attractive to both domestic and international lenders. Risk guarantees further improve the risk-return profile for private investors by covering potential losses, enabling financing for capital-intensive but high-impact projects, such as compressed biogas production and battery storage. An OECD evaluation found that guarantees accounted for 26% of all mobilized private finance between 2018 and 2020, demonstrating their effectiveness in scaling private investment.[70] De-risking renewable energy assets and building a bankable project pipeline is critical to attracting capital, as seen in successful blended finance applications across emerging markets.[71,72] When combined with concessional finance, risk guarantees provide the confidence needed to unlock private sector participation, accelerating investments in India's clean energy transition.

38. **Innovative financing mechanisms led by multilateral DFIs and international climate funds, such as the GCF, can help address macroeconomic risks while supporting underfunded clean energy technologies.** These institutions play a crucial role in providing hedging mechanisms to mitigate currency fluctuations and

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[68] Moody's affirms India's sovereign ratings, retains stable outlook | Reuters
[69] Ministry of Environment, Forest and Climate Change, "India: Fourth Biennial Update Report to the United Nations Framework Convention on Climate Change", 2024.
[70] Climate Finance Provided and Mobilised by Developed Countries in 2016-2020 : Insights from Disaggregated Analysis | Climate Finance and the USD 100 Billion Goal | OECD iLibrary (oecd-ilibrary.org)
[71] Cost of Capital for Renewable Energy Investments in Developing Economies - CPI (climatepolicyinitiative.org)
[72] Catalyzing Private Investments and Climate Finance to Turn Energy Transition Ambitions to Reality (worldbank.org)

incentivizing local manufacturing initiatives, thereby reducing the cost of importing clean energy equipment and strengthening supply chain resilience. Aligning these efforts with India's call for climate-specific grants and concessional loans as part of its BUR-4 update to UNFCCC can accelerate technology deployment, bridge financing gaps, and facilitate a just and sustainable energy transition. Blending GCF finance with MDB lending can provide a scalable model to unlock adequate concessional capital, ensuring that India receives the long-term, affordable finance needed to support its energy transition. Enhancing accessibility to international climate funds is crucial for financing technologies aligned with country-specific priorities. By simplifying fund application processes, improving transparency in allocation, and tailoring financing mechanisms to meet the unique needs of India's energy sector and technologies, international finance can become a more reliable and effective resource for driving systemic change.

2.5 Conclusion and opportunities for IGFF

39. **IGFF is designed to address financing barriers and accelerate India's clean energy transition by mobilizing long-term, low-cost capital and scaling underfunded technologies and applications.** Through concessional finance and innovative risk-mitigation mechanisms, IGFF would unlock investments in high-impact areas across energy, industry, transportation, and agriculture, ensuring alignment with India's climate and development priorities. GCF's involvement strengthens the facility's financial and institutional capacity, expanding its ability to drive systemic change in clean energy financing. Key opportunities for IGFF include:

- **Scaling underfunded clean energy technologies to enhance energy access and industrial decarbonization** – IGFF prioritizes battery storage, hybrid renewable systems, and decentralized clean energy applications to stabilize energy supply, improve rural livelihoods, and reduce fossil fuel dependence. These solutions increase grid resilience, ensure reliable electricity access, and mitigate climate risks, creating socio-economic benefits beyond emissions reductions.
- **Deploying concessional lines of credit to reduce investment risks and unlock capital** – By offering affordable, long-tenure financing, IGFF addresses high upfront costs and uncertain revenue streams, particularly for green hydrogen, battery storage, and decentralized renewable systems. Concessional capital bridges financing gaps, supports early-stage deployment, and ensures commercial viability while preventing unsustainable debt burdens.
- **Blending concessional and private capital to crowd in market-based financing** – IGFF expands private sector participation by combining GCF's concessional capital with commercial investments, ensuring a stronger risk-return balance for private investors. By targeting underfunded and high-risk technologies—rather than mature segments like utility-scale solar and wind—IGFF prevents market distortions while driving capital into emerging clean energy solutions.
- **Aggregating small-scale interventions into investable portfolios –** To expand financing for decentralized solutions, IGFF consolidates smaller, high-impact projects—such as off-grid solar pumps and DRE for rural applications—into a single investment portfolio. This approach enhances financial viability, making these projects more attractive to institutional investors and development finance stakeholders.
- **Leveraging GCF's concessional capital and technical expertise –** Blending GCF's capital with ADB's ordinary capital resources lowers the Weighted Average Cost of Capital (WACC) for green finance, making sub-commercial lending viable for high-impact clean energy projects. Additionally, GCF's experience in financial innovation and institutional capacity building would enable IGFF's partner DFIs to strengthen their green finance frameworks, align with global best practices, and scale climate-aligned lending.

40. **With GCF's support, IGFF would establish a scalable financing model to accelerate India's clean energy transition by deploying concessional credit lines and attracting private sector capital to support the next generation of clean energy technologies.** By lowering financing costs and mitigating investment risks, IGFF would unlock immediate funding for clean energy projects while ensuring a steady flow of capital to sustain their long-term deployment. Additionally, through a combination of concessional finance, risk-mitigation tools, and targeted institutional support, IGFF would help strengthen domestic financial institutions and improve access to capital for high-impact clean energy solutions. Its Technical Assistance (TA) component—which is detailed in the next chapter—would support DFIs in integrating green lending frameworks, assessing climate risks, and structuring effective financing mechanisms, ensuring that the financial system is equipped to scale climate investments efficiently.

3. Strengthening clean energy finance for India: The catalytic potential of domestic DFIs

41. **This chapter examines the feasibility and impact potential of implementing IGFF through domestic DFIs, assessing how they can serve as effective intermediaries for mobilizing climate finance to accelerate India's clean energy transition.** It provides a detailed profile of the three DFIs selected for IGFF —IIFCL, NABARD, and REC—analyzing their existing clean energy financing activities, institutional mandates, and alignment with national climate commitments. The chapter also evaluates their progress in integrating sustainable finance principles, their current portfolio composition, and sectoral priorities. Additionally, it identifies key institutional, financial, and operational challenges that constrain their ability to scale climate-aligned investments, drawing on insights from stakeholder consultations and secondary data analysis. Finally, it outlines the financial and capacity-building support required to strengthen DFIs' role in driving systemic change in India's climate finance ecosystem.

3.1 The need for a strong green domestic financial system to support the transition

42. **India's clean energy transition requires a fundamental shift in how finance is mobilized and allocated.** However, the financial system remains heavily reliant on domestic sources and debt financing, with investments primarily flowing into large-scale utility renewables. While international climate finance flows have increased slightly, total flows remain far below the USD 170 billion required annually to meet India's net-zero commitment. At the same time, as discussed in previous chapters, emerging clean energy technologies and applications remain significantly underfunded. These solutions face persistent financing gaps due to high capital costs, unproven business models, and a lack of concessional capital to support their development and deployment, limiting their scale-up despite their critical role in India's clean energy transition.

43. **In this context, greening India's financial system is not just about increasing the overall volume of clean energy investments; it must also strengthen the capacity of domestic financial institutions to more effectively channel capital toward the country's clean energy transition**—particularly toward underfunded, high-impact technologies. While there is no universally agreed definition, the Network for Greening the Financial System defines 'greening the financial system' as the "engagement of financial actors in (a) directing investments and loans towards environmentally sustainable goals and (b) managing risks associated with climate change and environmental challenges."[73] This requires embedding climate considerations into financial decision-making, improving risk assessment frameworks, and integrating concessional finance more systematically into lending structures to achieve viability and accelerating scaling up. At the same time, financial institutions must be better equipped to assess and support investments in emerging clean energy solutions that do not yet fit neatly within traditional lending models. Expanding access to concessional finance, aligning financial institutions with domestic sustainability reporting frameworks, and developing targeted de-risking mechanisms will be essential in unlocking private capital for these technologies. Strengthening these mechanisms will not only ensure a more diverse and resilient clean energy investment landscape but also enhance India's country-ownership in financing its net-zero transition—reducing dependence on external capital and fostering a stronger, more adaptive domestic financial ecosystem capable of supporting the next stage of the transition aligned with its development priorities.

44. **India has started implementing key regulatory and institutional reforms to integrate sustainability into its financial system, with the Reserve Bank of India – the country's central bank – playing a central role**

[73] Synthesis report on the greening of the financial system

in guiding banks toward mobilizing capital for green investments. Recognizing the critical role of domestic DFIs in financing renewable energy and low-carbon infrastructure, RBI, in coordination with the Securities and Exchange Board of India (SEBI) and major national banks, has begun strengthening climate risk integration, sustainable finance frameworks, and regulatory oversight.[74] SEBI, as India's primary financial market regulator, is responsible for developing sustainable investment guidelines, overseeing green bond issuances, and ensuring climate-related disclosures by listed entities, making its role essential in aligning financial flows with national decarbonization goals. Together, these reforms aim to enhance the financial system's ability to support an equitable and sustainable energy transition while improving resilience to physical and transition risks.[75] Accordingly, the following are the notable developments:

- **International collaboration:** The Reserve Bank of India (RBI) became a member of the Central Banks and Supervisors Network for Greening the Financial System (NGFS) in April 2021. Through this membership, the RBI aims to enhance its capacity to adopt international best practices and strengthen risk management in the financial sector. Additionally, it seeks to mobilize mainstream financial resources to support a sustainable economic transition.
- **Sustainable Finance Group and climate risk management:** The RBI has established a dedicated Sustainable Finance Group (SFG) to spearhead regulatory efforts in sustainable finance and climate risk. This group has also investigated the use of climate scenario analysis to identify vulnerabilities in the balance sheets and business models of entities regulated by the RBI. It aims to address gaps in their capacity to measure and manage climate-related financial risks effectively.
- **Integrating climate risks into financial stability monitoring:** In 2022, the RBI conducted a survey to evaluate how well major scheduled commercial banks were prepared to manage climate risks. While some progress was noted, the findings underscored the need for more systematic efforts. Subsequently, in July 2022, the RBI released a Discussion Paper on Climate Risk and Sustainable Finance to gather stakeholder feedback.[76] Following this, in February 2023, the RBI announced plans to issue guidelines covering (i) a framework for accepting green deposits, (ii) a disclosure framework for climate-related financial risks, and (iii) guidance on climate scenario analysis and stress testing.
- **Draft Framework for climate-related financial disclosures:** The draft framework mandates regulated entities to disclose climate-related financial risks and opportunities across four key areas: governance, strategy, risk management, and metrics and targets. This initiative is designed to facilitate early assessment of these risks and opportunities while promoting market discipline.
- **Priority Sector Lending (PSL) policy:** Over the years, the PSL policy has evolved to address the credit needs of sectors that significantly contribute to economic growth and align with national priorities such as poverty alleviation, job creation, and inclusive development. In April 2015, renewable energy was added as a distinct category under the PSL framework to emphasize its growing importance. Under this policy, project developers can borrow bank loans up to a limit of INR 30 crore for purposes like solar-based power generators, biomass-based power generators, windmills, micro-hydel plants and for non-conventional energy-based public utilities, viz., street lighting systems and remote village electrification etc. For individual households, the loan limit is INR 10 lakh per borrower. It also makes special provisions to improve lending for weaker sections, such as small and marginal farmers, self-help groups, and distressed persons occupied in rural livelihoods in agriculture and related activities.[77]

45. **Despite these regulatory advancements, systemic barriers persist among domestic DFIs, limiting their ability to assess climate risks, integrate sustainability into lending portfolios, and mobilize investments for emerging clean energy technologies.** While some progress is being made, these gaps constrain the scalability of

[74] RBI, "Mitigating Climate Change Risks and Fostering a Robust Ecosystem for Sustainable Finance", 2024.
[75] RBI, "Mitigating Climate Change Risks and Fostering a Robust Ecosystem for Sustainable Finance", 2024.
[76] RBI, "Report of the Survey on Climate Risk and Sustainable Finance", 2022.
[77] RBI, "Master Directions – Priority Sector Lending (PSL) – Targets and Classification", 2024.

climate finance and limit access to international concessional capital, making it imperative to accelerate efforts to align with global best practices. Key challenges include:

- **Information asymmetry on climate risks.** A major barrier for financial institutions is the lack of robust data and risk assessment tools to evaluate climate risks effectively. The RBI's 2022 survey revealed that 95% of financial institutions lacked adequate data to incorporate climate risks into their investment decisions.[78] This creates uncertainty in project financing, making it difficult for DFIs and commercial banks to quantify risks, structure green investments, and assess climate-related impacts on portfolios. Without stronger data frameworks, financial institutions will struggle to effectively price risk and allocate capital to clean energy projects.
- **Lack of a standardized green taxonomy.** India currently lacks a unified taxonomy to define green and sustainable investments, making it difficult for financial institutions to classify, report, and assess the impact of green finance flows. This lack of standardization leads to inconsistencies in tracking and categorizing projects, affecting transparency and investor confidence.[79] Recognizing this challenge, the Government of India announced in the Union Budget 2024-25 the development of a national climate finance taxonomy, which will streamline definitions and enhance alignment with global sustainable finance frameworks.[80] However, until this is fully implemented, financial institutions—including DFIs—will continue to face difficulties in structuring and scaling climate-aligned investments.
- **Limited technical capacity to build a pipeline of bankable projects.** The shortage of technical expertise within DFIs and commercial banks is a significant constraint. **Many financial institutions lack the capacity to assess, structure, and finance clean energy projects beyond utility-scale renewable installations, which have already achieved commercial viability.[81]** This gap is further exacerbated by fragmented decision-making and poor coordination among stakeholders, making it challenging to develop a robust pipeline of bankable clean energy projects. Without dedicated training and institutional capacity-building, DFIs will struggle to expand their role in climate finance effectively.
- **Limited progress in climate-related risk disclosures.** While some banks and financial institutions have initiated sustainability reporting, climate-related financial disclosures remain inconsistent and misaligned with global frameworks. The RBI's 2022 survey found that only 45% of respondents had formal norms (defined as internal and non-enforceable guidelines for carrying out climate risk assessments) for assessing climate-related risks, and most banks lacked dedicated sustainability divisions. Public sector banks, in particular, lag in adopting internationally recognized disclosure frameworks, such as the Task Force on Climate-related Financial Disclosures (TCFD). Strengthening mandatory disclosure requirements and ensuring alignment with international reporting frameworks will be crucial to enhancing market transparency, investor confidence, and the overall credibility of India's green finance ecosystem.

3.2 Domestic DFIs are primary recipients of IGFF support

46. **IGFF will address these gaps by providing concessional finance while also strengthening the capacity of domestic DFIs to integrate green lending practices into their portfolios, positioning them as the primary recipients of the facility's support.** Domestic DFIs are uniquely positioned to drive this transformation. As publicly owned yet financially autonomous institutions, they operate with a legal mandate to advance national development priorities, making them critical vehicles for financing the clean energy transition.[82] The

[78] RBI, "Report of the Survey on Climate Risk and Sustainable Finance", 2022.
[79] Climate Policy Initiative, "Landscape of Green Finance in India 2024", 2024.
[80] Down To Earth, "Budget 2024–25: India Introduces Climate Finance Taxonomy Amid Greenwashing Concerns", 2024.
[81] Based on an analysis of annual reports from select domestic DFIs and insights gathered from consultation workshops conducted as part of this study..
[82] Investment Climate Reform Facility, *"National DFIs: Critical allies for climate action: Why and how can they be more involved in climate finance?"*, 2021.

Independent Expert Group on MDB Evolution, convened during the G20 Summit in 2023, has further emphasized the role of MDBs like ADB and World Bank in working closely with domestic DFIs in emerging markets. Their recommendation underscores the strategic importance of leveraging DFIs to maximize development and climate outcomes, as they possess the institutional expertise, market reach, and policy alignment needed to scale clean energy investments more effectively than traditional private and public financing channels. Hence, by positioning them as the primary recipients, the facility can ensure alignment with India's national climate goals while enhancing the efficiency and impact of its financial flows. This approach also strengthens the broader national finance architecture, equipping it to mobilize private and institutional capital at scale in support of the transition.

47. Some of the unique advantages such an approach provides are as follows:

- **Domestic DFIs are mandated to support the national climate and development agenda, including sectoral priorities and targets.** They are mandated by their respective governments to provide long-term financing to sectors that promote a country's sustainable and economic development, particularly directed towards projects or sectors of the economy (or state-of-the-art technologies) that are currently underserved. By channeling climate finance through these institutions, funds are more likely to support India's commitments under the Paris Agreement and its NDCs while ensuring country ownership. Some of India's DFIs are already contributing to the country's target of achieving 500 GW of non-fossil fuel energy capacity by 2030 through investments in utility-scale installations. As of 2023, India Infrastructure Finance Company Ltd., a national DFI dedicated to financing India's infrastructure ambitions and targets, had sanctioned ~17 GW of RE projects, which represented ~11% of the country's total installed capacity.[83] The Rural Electrification Company (REC) Limited has emerged as a critical DFI for the entire power sector, providing loans for various projects, including renewables. REC has successfully raised three green bonds with different tenors, and the proceeds are being used to finance solar, wind, renewable purchase obligations, and low-carbon transportation projects. It has also established a 'Green Portfolio' in line with the Green Bond framework for monitoring and evaluation. As of March 31, 2024, REC had sanctioned approximately 7.5 GW of renewable energy projects through bond proceeds.[84] In addition, there are several other DFIs (structured as PSUs) making progress in aligning their core strategy, decision-making, lending, and investment with national and global climate agreements such as the Paris Alignment, making them fail-proof conduits to direct international climate flows.
- **They possess a deep knowledge of local markets and hold relationships with a wide network of local financiers and project developers.** Their regional presence and relationships with local stakeholders enable them to identify and support high-impact projects that align with both local needs and national priorities. For example, The National Bank for Agriculture and Rural Development (NABARD) has played a critical role in implementing projects at the intersection of climate change, rural development, and poverty alleviation in line with national priorities. Through its financing and refinancing activities, NABARD supports credit lines for initiatives such as the Rural Infrastructure Development Fund, Warehouse Infrastructure Fund, and Dairy Processing and Infrastructure Development Fund. Its direct support for watershed and spring shed development projects in FY2023 alone covered approximately 88,000 acres, positively impacting around 37,000 families.[85] In addition to being an Accredited Entity for the GCF and the Adaptation Fund, NABARD also acts as the National Implementing Entity for the National Action Plan for Climate Change under the Ministry of Environment, Forest, and Climate Change. Given their close relationship with the government, domestic DFIs can influence policy directly by bringing relevant inputs to policymakers about the impacts and implementation of various policy options because of their involvement and interaction with the financial and non-financial private

[83] IIFCL, *"Annual Report: 2022-2023"*, 2023.
[84] REC, *"Annual Report: 2023-24"*, 2024.
[85] NABARD, *"Annual Report 2023-24"*, 2024.

sectors. This role is vital in contributing to creating the necessary conditions to scale up domestic climate finance.

- **Given their higher risk appetite, these DFIs are particularly relevant for leveraging domestic and international private capital to deploy innovative financing, especially crucial for early-stage technologies.** They are expected to complement, and as a result, "crowd in" private finance by providing appropriate financial and non-financial instruments[86]. For instance, under the "Partial Risk Sharing Facility for Energy Efficiency" (PRSF) project supported by the World Bank, SIDBI provided risk coverage to Participating Financial Institutions (PFIs) lending to energy efficiency projects, particularly through energy service companies (ESCOs). This USD 43 million program, with a USD 37 million risk-sharing facility, helped de-risk loans and a USD 6M technical assistance program to build the capacity of MSMEs to implement energy-saving projects, ultimately enabling them to access much-needed finance for energy efficiency improvements. As of 2020, The PRSF project had mobilized USD 53 million in energy-efficient sub-projects, cutting 95,000 tons of CO_2 annually and demonstrating the leverage effect of loan guarantees by attracting private capital 3.35 times the public investment of USD 15.8 million. It has also encouraged commercial banks to view ESCOs as viable borrowers.
- **Mainstreaming climate change into domestic DFIs' operations and lending activities will drive transformational impact, leading to more sustainable and improved developmental and financial outcomes in the region.** By directly supporting domestic DFIs in their greening journey, there is an opportunity to fundamentally move the needle on how the domestic markets approach financing the clean energy transition, but also more broadly low-carbon and climate-resilient growth. This is also because DFIs not only provide funding to projects but also play an important role in creating examples of resource mobilization for climate finance, thus encouraging domestic and international private sector investors to engage in the project pipelines and investment opportunities developed by DFIs. Their participation in the above areas can encourage commercial banks and investors to adopt sustainable financing practices as well.[87] However, it needs to be acknowledged here that aligning financial flows across all activities and business lines, in addition to delivering and increasing climate finance efforts, requires transformational changes within their institutions. These will include the adaptation of strategies and operations to phase out activities inconsistent with the goals of the Paris Agreement, and new measures to contribute whenever possible to national low-GHG climate-resilient development while meeting existing lending priorities.

Table 5 below summarizes their unique advantages over conventional channels for directing climate finance.

Table 5. Comparative advantage of national DFIs over other channels

Category	DFIs	MDBs	Public sector banks	Private sector banks
Mandate and Policy Alignment	• Directly aligned with national low-carbon, climate-resilient policies • Mandated to support government initiatives across sectors • Flexible to adapt to emerging priorities	• Alignment via country strategies; may differ in priorities • Broad international development mandate • Longer response to emerging priorities times	• Indirect alignment through regulations • Commercial mandate to seek profits while providing public services • Less flexibility to shift focus quickly	• Limited alignment unless commercially attractive • Profit-driven mandate • Minimal strategic focus on national climate objectives

[86] Inter-American Development Bank, "The Role of National Development Banks in Catalyzing International Climate Finance", 2013
[87] Anna Roy, "Innovative financing: the case of India Infrastructure Finance Company", in World Bank Blogs, 2025.

Governance structures	• Wholly or partially government-owned entities under national laws • Strong oversight by government ministries	• International organizations governed by member countries • Multi-country oversight with diverse interests	• State-owned but operate commercially • Governed by banking regulations and central bank oversight	• Privately owned institutions • Governed by shareholders focused on profitability
Financial instruments and flexibility	• Wide range of tailored instruments: concessional loans, grants, guarantees • Flexible structuring to meet project needs	• Provide standardized loans and grants except for occasional innovations limited by policies • Less flexible; longer approval processes	• Standard financial products; largely loans and credit lines • Risk-averse with less flexibility	• Commercial loans at market rates • Higher rates, shorter tenures; reluctant in unproven sectors unless guarantees are provided[88]
Risk appetite and capacity	• Higher risk tolerance for developmental projects • Finance emerging/unproven technologies	• Moderate risk; prefer large, proven projects, unless through SPVs • Limited engagement in high-risk areas	• Conservative; focus on established sectors • Limited capacity for innovative projects	• Low risk tolerance; focus on profitability • Limited expertise in climate-specific areas
Local expertise and barriers addressed	• Deep local market knowledge; presence in rural and other underserved areas • Address market/non-market barriers via capacity building	• Rely on partnerships for local insights • Less direct engagement at grassroots levels	• Broad network but less specialized in climate issues • Limited capacity to address specific barriers	• Operational expertise with limited need for sectoral depth • Do not address market failures

Despite their critical role as providers of low-cost, long-term project debt, domestic DFIs remain underutilized in mobilizing international climate finance and scaling concessional capital for clean energy. Debt financing accounted for 50% of total climate finance flows in FY 2019/20, yet low-cost project debt made up just 19%, with DFIs representing only a small share of these flows. While public sector financial institutions—including both DFIs and commercial lenders—account for 60% of low-cost project debt, much of this financing remains concentrated in large-scale renewable projects, limiting support for emerging clean energy technologies. Meanwhile, international climate finance from public sources is largely bypassing domestic DFIs, with bilateral and multilateral DFIs accounting for 35% and 24% of total flows, respectively, primarily through ODA and OOF channels that finance projects directly rather than routing them through domestic DFIs. At the same time, they provide opportunities to attract larger international private capital flows aligned with country priorities. For instance, Foreign Direct Investments (FDI) accounted for 20% of global green finance in the same period but represented only 3% of total FDI inflows to India. A more coordinated approach to leveraging domestic DFIs can significantly improve their ability to attract international concessional finance while ensuring capital flows are aligned with national priorities—a key opportunity for IGFF. Expanding their access to concessional finance can further lower the weighted average cost of capital (WACC) for emerging clean energy technologies, making it more viable to finance projects that are not yet commercially competitive while improving affordability and scaling deployment.

(This portion has been redacted in accordance with the GCF Information Disclosure Policy, as the portion is confidential under the disclosure policy of the Accredited Entity)

[88] Climate Policy Initiative, *"Landscape of guarantees for Climate Finance in EMDEs"*, 2024.

3.3 Profiles of shortlisted DFIs for IGFF

48. **To better understand the current domestic lending landscape and capacity gaps, IGFF conducted detailed consultations with leading DFIs in India, focusing on those with lending mandates aligned with the facility's objective of mobilizing finance to accelerate the country's clean energy transition (ref. to Annex 7).** The following section provides an in-depth overview of the first set of DFIs shortlisted[89] for IGFF—India Infrastructure Finance Company Limited (IIFCL), National Bank for Agriculture and Rural Development (NABARD), and Rural Electrification Corporation (REC)—detailing their role in financing the clean energy transition, current portfolio composition, climate-related targets, and efforts to align operations with green finance principles. It also highlights the key challenges they face in scaling clean energy investments, which directly informed the design of project-specific capacity support for priority technologies and applications (detailed further in Chapter 4).

IIFCL

49. **IIFCL, a Government of India enterprise, provides long-term financial assistance for viable infrastructure projects, playing a crucial role in the nation's low-carbon transition.** With a mandate to cover about 30% of project debt, it mobilizes significant long-term debt while leaving the remaining 70% to be financed by the normal banking system.[90] This model not only facilitates long-term lending but also signals the banking sector to proactively participate in infrastructure financing. Additionally, IIFCL's involvement in Public-Private Partnerships (PPP) enhances the potential for successful project implementation by leveraging both public and private sector strengths.[91] In the energy space, IIFCL has been instrumental in developing approximately 65 GW of capacity, which represents about 17% of India's total installed capacity.[92] This underscores its substantial impact on the renewable energy sector. The company finances both greenfield and brownfield projects through diverse products such as Direct Lending, Subordinate Debt, Takeout Finance, Refinance, Credit Enhancement Guarantees, InvITs, and Bonds. Notably, IIFCL's Takeout Finance Scheme and Credit Enhancement Scheme are innovative solutions designed to mitigate risks and address the asset-liability mismatches faced by banks, which would be beneficial in facilitating greater investments in RE infrastructure in the country.

50. **IIFCL is a key financier of green infrastructure, with renewable energy projects—primarily solar and wind—accounting for 70% of its green portfolio in 2022-23.** As part of its green energy initiatives, IIFCL provides financial support through various modalities such as direct lending, take-out lending, refinance, credit enhancement, bonds, Infrastructure Investment Trusts (InVITs), and the Pooled Municipal Debt Obligation (PMDO) for renewable energy development in India. Till 31st March 2023, IIFCL sanctioned INR 26,258 Crores in Renewable energy generation sector with total disbursements of INR 14,697 Crores; 85% of their portfolio is A, AA and AAA projects.[93] Since the establishment of its green energy initiatives in 2006, and as of March 31, 2023, the institution has contributed to the development of approximately 21 GW of renewable energy capacity—accounting for 5.96% of the country's total installed capacity of 125 GW by the end of FY 2022-23. During this time, IIFCL has provided partial financing for over 200 renewable energy projects, contributing to the avoidance of 39.8 million metric tonnes of CO_2 emissions annually and generating approximately 10,000 job opportunities across both skilled and unskilled worker categories. It is also expanding into other sectors relevant for India's clean energy transition such as green buildings, MRTS, and the greening of airports and railways. For instance, IIFCL extended financial assistance (under lender's consortium arrangement) to Pune Metro Rail Transport

[89] Additional DFIs may be onboarded in future phases, subject to a detailed evaluation of their Environmental and Social Safeguards (ESS) frameworks and alignment with IGFF's lending priorities and structures. Ensuring this alignment would be critical before they can access IGFF support.
[90] IIFCL: State-run IIFCL to offer innovative infrastructure financing - The Economic Times (indiatimes.com)
[91] Innovative financing: the case of India Infrastructure Finance Company (worldbank.org)
[92] India Infrastructure Finance Company Ltd (theceo.in)
[93] Stakeholder consultation

project by sanctioning term loan of INR 1450 Crores and disbursement of 262 crores till 31st March 2023.[94] **While IIFCL has expressed interest in emerging technologies like green hydrogen, battery storage, and waste management, its exposure to these sectors remains limited due to risk aversion and insufficient institutional capacity to evaluate high-risk, capital-intensive projects**.[95]

51. **To strengthen its green finance capabilities, IIFCL has introduced a Green Bond Framework and has updated its Environmental and Social Safeguards Framework (ESSF) to enhance risk assessments.** Its Climate Strategy for 2030 commits to directing at least 50% of incremental lending toward green infrastructure while phasing down fossil fuel investments. As of September 2024, green energy projects comprised 15% of its portfolio, with a target of 20% by FY2025.[96] As IIFCL scales its investments, including green bond issuances to achieve its target of allocating 50% of lending to green sectors by 2030, it requires enhanced capacity to channel funding beyond large-scale renewable energy projects, along with increased access to concessional capital.

52. **However, to effectively scale its role in India's clean energy transition, IIFCL must address key institutional challenges.** The company lacks formal policies and targets to assess and mitigate its environmental impact across energy, waste, water, and biodiversity—both within its operations and lending portfolio—despite its 2030 net-zero target, which currently applies only to Scope 1 and 2 emissions. Additionally, its procurement practices are not aligned with ESG standards or any recognized sustainability framework, as it is still in the early stages of integrating ESG considerations.[97] To bridge these gaps, IIFCL has identified the need for technical assistance in project structuring and investor engagement, particularly in emerging sectors, to enhance project viability in line with international best practices. It also requires concessional financing to scale investments in green hydrogen, and battery storage. While IIFCL currently lacks mechanisms to track and support women entrepreneurs, it has expressed a willingness to develop targeted programs, contingent on access to concessional resources.[98] Strengthening these areas will be critical to expanding IIFCL's impact, improving its green finance capabilities, and attracting a broader pool of investors.

NABARD

53. **NABARD is a pivotal financial institution in India's climate financing landscape. Established** in 1982 under an Act of Parliament, NABARD is the apex development bank tasked with promoting sustainable and equitable agriculture and rural development.[99] The recently launched Climate Strategy 2030 aims to address the increasing need for green financing in India, focusing on four key pillars: accelerating green lending across various sectors, market-making to foster a broader sustainable finance ecosystem, internal green transformation of NABARD, and strategic resource mobilization to ensure adequate funding for climate initiatives.[100] Additionally, NABARD's re-accreditation as a Direct Access Entity of GCF enables it to channel significant international climate finance towards India's ambitious climate goals. The establishment of a Technical Support Unit with assistance from the Asian Development Bank further enhances NABARD's capacity to implement effective climate action initiatives.[101] These efforts position NABARD as a crucial institution in driving India towards a resilient and sustainable economic future. Its extensive network and deep reach into rural areas make it an ideal partner for channeling concessional finance to projects that enhance climate resilience and support low-carbon development in rural India.

54. **NABARD plays a critical role in financing clean energy solutions in rural India, with a strong focus on climate adaptation and mitigation.** As the apex rural finance institution, NABARD provides credit and

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[94] AnnualReportFY232pdf10102023124407.pdf
[95] Stakeholder consultation
[96] ICRA ESG Ratings Limited, "India Infrastructure Finance Company Limited (IIFCL): Rating assigned", January 2025.
[97] Ibid.
[98] Stakeholder consultation.
[99] NABARD - National Bank For Agriculture And Rural Development
[100] 2904240453nabard-releases-climate-strategy-2030.pdf
[101] NABARD - National Bank For Agriculture And Rural Development

refinancing for decentralized renewable energy (DRE) applications, sustainable agriculture, and rural infrastructure, distinguishing it from PSUs like REC and IIFCL, which focus on grid-scale renewables and urban clean energy projects. NABARD's financing supports solar-powered irrigation, rural electrification, micro-irrigation systems, and compressed biogas (CBG) to a limited extent. It is also developing new green financial products, including climate-resilient dairy, solar agri-pumps, rural electric mobility, and rooftop solar for rural homes. Additionally, NABARD serves as an Accredited Entity for the GCF and Adaptation Fund, and acts as the National Implementing Entity for the National Action Plan for Climate Change, working with state governments to align projects with their State Action Plans for Climate Change (SAPCCs). As of March 2024, NABARD has 40 climate change projects at various stages of implementation, with a total financial outlay of ₹1,971.56 crore.

55. **NABARD has been financing various projects relevant for rural India's clean energy transition under respective national missions.** In FY2024, NABARD financed ₹1,063 crore for solar-powered irrigation projects under PM-KUSUM and ₹617 crore for 20,000 solar pumps under Saur Sujala Yojana in Chhattisgarh. The Micro Irrigation Fund (₹5,000 crore) has been operationalized to support small landholder farmers beyond PM Krishi Sinchayee Yojana. NABARD's Infrastructure Development Assistance (NIDA) facility is financing four solar and five wind energy projects across seven states, while it is also expanding CBG financing under the SATAT scheme, integrating rural waste management with renewable energy generation. Under the Warehouse Infrastructure Fund (WIF), NABARD provides loans and subsidies for post-harvest infrastructure, including solar-powered cold storage and processing units. By FY2024, NABARD's total infrastructure financing stood at ₹8.2 lakh crore, with ₹6.2 lakh crore disbursed. In the dairy sector, NABARD has financed 32 projects under the Dairy Processing and Infrastructure Development Fund (DIDF), allocating ₹3,015 crore toward modernizing milk processing and supply chain infrastructure, with an increasing focus on RE-powered DRE applications in dairy operations.

56. **To align with its climate finance objectives, NABARD has developed an internal green taxonomy to systematically classify its lending portfolio.** In a significant stride towards sustainable development, NABARD unveiled its Climate Strategy 2030, which is structured around four key pillars to meet India's climate finance needs: (i) Accelerating Green Lending across sectors, (ii) Playing a broader Market-Making Role, (iii) Internal Green Transformation of NABARD, and (iv) Strategic Resource Mobilization.[102] However, the institution is still in the process of fully tagging its portfolios in line with its green taxonomy and lacks the capacity to perform due diligence for emerging clean energy technologies, which limits its ability to effectively achieve its ambitions under its climate strategy. NABARD has sought technical assistance to enhance its ability to monitor the impact of its investments, streamline impact reporting through digital dashboards, and integrate best practices for pipeline development and risk assessments.

57. **Despite these efforts, NABARD faces structural barriers in scaling its clean energy financing.** With the National Adaptation Fund for Climate Change (NAFCC) winding down, concessional finance is needed to help states transition from grant-based adaptation projects to affordable loans. NABARD has also requested differential borrowing rates for adaptation and mitigation projects to ensure that climate resilience investments remain financially viable, while also helping with addressing the challenge of hedging costs that accompany international finance borrowing. The institution also requires greater access to concessional capital to expand support for emerging clean energy applications such as solar-powered rural enterprises, bioenergy, and climate-smart irrigation systems.

58. **Addressing these challenges will be critical for NABARD to deepen its role in India's clean energy transition, particularly in sectors that directly benefit small and marginal farmers, rural enterprises, and decentralized energy users.** Targeted capacity-building efforts, improved project pipeline development,

[102] 2904240453nabard-releases-climate-strategy-2030.pdf

concessional financing, and impact tracking mechanisms will be key to ensuring NABARD can effectively mobilize finance for rural clean energy solutions that contribute to both climate mitigation and adaptation goals.

REC

59. **REC Limited is a public sector enterprise that provides financial assistance to the power sector and non-power infrastructure projects in India.** REC's extensive experience in financing renewable energy projects, along with their recent initiatives, underscores their capability to drive large-scale sustainable projects. Their receipt of a USD 200 million green loan from Deutsche Bank AG[103] highlights their capacity to secure and manage international climate finance. Furthermore, REC's collaboration with Bharat Heavy Electrical Limited (BHEL) to develop utility-scale renewable energy projects demonstrates their commitment to expanding India's renewable energy infrastructure.[104] The partnership with the National Investment and Infrastructure Fund Limited (NIIFL) to create innovative funding solutions further establishes REC's strategic role in advancing India's clean energy goals.[105] Their comprehensive approach, which includes supporting projects that meet stringent environmental standards and reduce carbon emissions, aligns perfectly with the facility's objectives of promoting low-carbon development and enhancing climate resilience. In 2023, REC Limited was awarded the SKOCH ESG Award in the Renewable Energy Financing category[106], underscoring its commitment to sustainable finance and renewable energy projects.

60. **REC plays a critical role in financing India's clean energy transition, aligning its investments with the country's climate action goals to expand renewable energy capacity and reduce carbon emissions.** The company deploys green loans for project financing and re-financing, including through issuance of green bonds, to both state and private sector entities for renewable energy generation, storage, low-carbon transportation, and, to a limited extent, clean tech manufacturing. As part of its strategic expansion, REC is positioning clean energy as a central pillar of its business growth, aiming to increase the share of renewables in its loan portfolio from 8% to 30% by 2030. REC has implemented an ESG policy that integrates environmental impact considerations into its operational and financial decision-making. It plans to align its climate risk assessments and disclosures with the Task Force on Climate-Related Financial Disclosures (TCFD) framework, in line with emerging regulatory expectations. Furthermore, it incorporates Environmental, Health, Safety, and Social (EHSS) considerations into loan agreements to strengthen sustainability compliance.

61. **In FY 2023-24, REC saw a 533% year-on-year increase in its renewable energy project sanctions, approving loans worth INR 1,36,516 crore across 82 projects in both public and private sectors.** These projects include solar (4,423 MW), wind (917 MW), hybrid wind-solar (1,775 MW with battery storage), large hydro (4,876 MW), and pumped storage (5,450 MW). Additionally, REC has sanctioned funding for solar module and wind turbine manufacturing, compressed biogas (CBG) production, green hydrogen projects, and e-mobility initiatives, including procurement of 5,750 electric buses. Despite this expansion, REC's renewable energy financing remains largely concentrated in large-scale solar and wind projects, which account for 70% of its clean energy portfolio by the number of projects financed, highlighting the need for greater support to emerging technologies.[107] REC's annualized cost of funds in FY 2023-24 stood at 7.13%, with INR 39,066 crore raised through bonds at an average cost of 7.60%—12 basis points lower than similarly rated CPSEs. However, REC faces challenges in securing long-tenure, low-interest debt to support large-scale renewable energy investments. The company's lending rates range from 8.95%-10.20% for state sector renewables and 9.2%-10.20% for private sector renewables, with slightly higher rates for pumped storage projects.[108]

[103] REC Ltd. a power financing PSU, has successfully availed a green loan of 31.96 Billion Japanese Yen (JPY) (equivalent to USD 200 million) from Deutsche Bank AG to finance eligible green projects in India. (aninews.in)
[104] REC, BHEL Forge Alliance for Renewables in India (constructionworld.in)
[105] pib.gov.in/PressReleaseIframePage.aspx?PRID=1999861
[106] Awards (recindia.nic.in)
[107] Annual Report 2023-24
[108] Stakeholder consultations

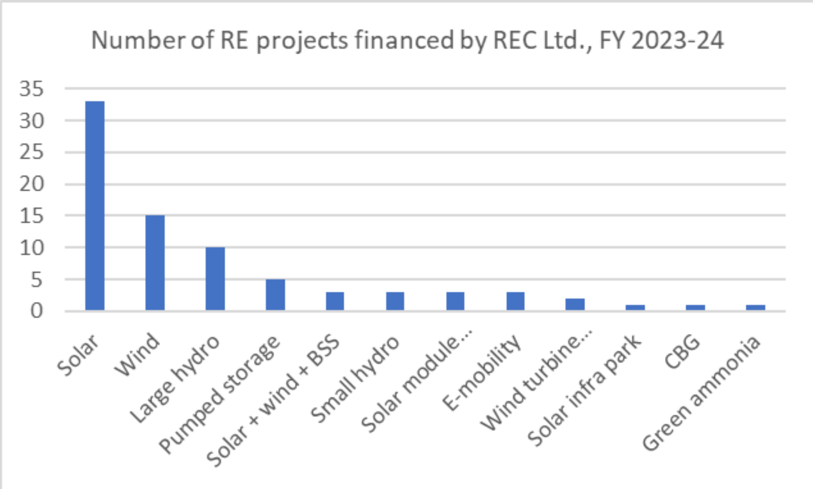

Figure 11. Project financing by REC in FY 2023-24 (total number of projects)

62. **REC has been a key player in India's green bond market, adhering to the Climate Bonds Initiative's Green Bond Framework and managing a dedicated Green Portfolio with a structured internal tracking system.** To date, REC has raised USD 1.2 billion and JPY 61.1 billion through green bonds, primarily targeting solar, wind, and renewable purchase obligations, with some funding directed towards low-carbon transportation. The states benefiting from these funds include Rajasthan, Karnataka, Telangana, and Gujarat for solar, and Tamil Nadu for wind energy. In April 2023, REC issued a landmark USD 750 million green bond, the largest tranche ever by a South and Southeast Asian issuer post India's G20 presidency.[109] However, due to the current high-interest rate environment in the UK, EU, and the US, REC has put foreign borrowing through green bonds on hold. This challenge underscores the need for alternative concessional financing mechanisms to sustain REC's renewable energy lending at scale.

63. **While REC has significantly expanded its renewable energy financing, emerging technologies remain underfunded, with renewable energy accounting for just 12% of its total lending—well below its 30% target for 2030.[110]** The majority of REC's clean energy financing continues to flow toward large-scale solar and wind projects, with limited investment in integrated solar-wind-BESS, CBG

64.

65. , green hydrogen, and clean tech manufacturing for solar modules and wind turbines. To bridge this gap, REC requires support in conducting project viability studies and structuring financing instruments to develop a strong pipeline for these emerging sectors. Additionally, while REC is strengthening its ESG frameworks and reporting practices, further alignment with global best practices, such as TCFD and sustainability-linked financing mechanisms, is needed. Given REC's goal to expand clean energy lending to 30% of its portfolio by 2030, targeted concessional financing and technical assistance would be crucial in unlocking investment for underfunded clean energy technologies, improving risk assessment frameworks, and enhancing project viability for financing.

3.4 Intervention areas to enhance DFI capacity for green lending

66. **While IIFCL, NABARD, and REC are actively engaged in financing clean energy projects, their ability to scale investments in emerging clean energy technologies remains constrained.** REC, for example, has committed to expanding its green finance portfolio and has raised a little more than USD 1 billion through green

[109] Annual Report 2023-24
[110] PowerPoint Presentation

bonds, yet its current financing remains concentrated in conventional renewables, with limited exposure to RTC renewables, battery storage, and industrial decarbonization solutions. Similarly, NABARD has deployed some concessional finance for rural renewable energy projects but faces challenges in expanding financing for decentralized clean energy applications due to a lack of dedicated instruments and technical expertise. Despite their deep understanding of local market dynamics and strong networks with rural micro-finance institutions and non-banking financial companies (NBFCs), these DFIs struggle to effectively leverage these relationships to structure and direct financing toward emerging clean energy technologies, as highlighted in IGFF's stakeholder consultations (ref. Annex 7).

67. **Through stakeholder consultations, these DFIs have identified key challenges that hinder their ability to accelerate clean energy financing at the scale required.** A major constraint is the lack of a strong pipeline of bankable projects in emerging clean energy areas, compounded by the need for support in structuring financial instruments tailored to these technologies that are low-cost and offer longer tenor periods. While DFIs have extensive networks with rural cooperatives and NBFCs, they require further support in identifying and engaging the right stakeholders to structure projects effectively and ensure alignment with financing needs. Additionally, DFIs require technical assistance to assess the economic and financial viability of these projects, ensuring their long-term sustainability and scalability. The absence of clear green finance taxonomies and standardized climate-related disclosure frameworks further limits their ability to track, categorize, and report on climate-aligned investments, constraining access to concessional finance and investor confidence.

68. **To address these gaps, IGFF will provide targeted financial and capacity-building support** to enable DFIs to expand their clean energy lending portfolios, enhance risk management practices, and integrate climate-aligned financing strategies. This includes:

a) **Providing concessional lines of credit to DFIs** (For further details on the need for concessional finance to accelerate the deployment of emerging technologies, refer to Section 2.3)

    a. IGFF will design and offer concessional loan products to DFIs to finance emerging clean energy technologies within its priority areas aligned with DFI's financing mandate.

    b. These financial products will help address the high capital costs and long payback periods associated with battery storage, RTC renewables, green hydrogen, and other clean energy solutions.

    c. By lowering the cost of capital, concessional financing will de-risk investments, improve affordability, and enable DFIs to extend more favorable lending terms to project developers.

b) Building institutional and technical capacity for project origination and financing

    a. Establishing Project Implementation Units (PIUs) within participating DFIs to support project preparation, due diligence, evaluation, and execution.

    b. Developing standardized loan documentation and operational frameworks to streamline project approvals and enhance efficiency.

    c. Creating monitoring systems to track project performance, ensuring compliance with financial, technical, and environmental safeguards.

    d. Facilitating market assessments, stakeholder engagements, and capacity-building workshops to strengthen DFIs' ability to structure financing for emerging clean technologies.

    e. Strengthening internal guidelines and practices on climate risk management and green lending frameworks (including taxonomies for green tagging).

c) **Training DFIs in climate risk assessment and management to improve investment decision-making for clean energy projects**

a. Supporting compliance with domestic climate-related financial disclosures and aligning reporting with international frameworks, such as TCFD, ISSB, and the EU Sustainable Finance Taxonomy.

b. Defining clear criteria for green lending, enabling consistency across DFIs' financing strategies and ensuring better tracking of climate finance flows.

c. Enhancing DFIs' capacity to finance women-led clean energy projects, integrating gender-responsive finance practices.

d. Facilitating peer learning through roundtables and networks, encouraging collaboration between DFIs and commercial banks.

d) Policy engagement and advocacy for systemic change

a. Engaging in dialogues with policymakers and regulators to strengthen green lending frameworks and sustainable finance policies.

b. Advocating for gender-responsive financing mechanisms to improve inclusivity within clean energy financing.

c. Developing policy briefs and case studies on green lending, climate risk integration, and disclosure standards, providing recommendations for regulatory and institutional reforms based on learnings from IGFF implementation.

69. **By addressing the institutional and financial barriers detailed in this chapter, IGFF will enable DFIs to move beyond conventional renewable energy financing and play a central role in accelerating India's energy transition.** Ensuring clear climate risk assessment mechanisms, standardized reporting frameworks, and access to concessional finance will be crucial in strengthening their ability to attract international investment and scale clean energy projects at the required pace. Without such interventions, renewable energy will remain a niche transaction within their portfolios rather than becoming a mainstream focus of their lending strategies. This would limit their ability to expand climate-aligned investments, ultimately constraining their contribution to India's net-zero goals.

4. Assessment of priority technologies for IGFF

70. **This section provides a detailed assessment of the six priority technologies identified for IGFF support, evaluating their role in India's clean energy transition, projected market potential, and associated climate and socio-economic co-benefits.** It also examines the financial, technical, and capacity-related barriers hindering their large-scale deployment and outlines how IGFF can address these challenges through concessional finance and technical assistance, including by leveraging GCF resources. Beyond direct investment support, IGFF aims to strengthen the national financial sector's capacity for green lending, ensuring the long-term sustainability and scalability of climate-aligned investments.

71. **The selection of these priority technologies was informed by targeted consultations with the three domestic DFIs selected for IGFF (ref. Section 3.3).** These discussions, guided by the list of priority technologies from Section 2.3, helped refine IGFF's focus areas by ensuring alignment with DFI financing priorities and India's clean energy transition needs. The consultations also provided deeper insights into the challenges limiting deployment, including investment risks, policy gaps, and institutional constraints (Annex 7 provides details on the stakeholder consultation process and outcomes).

72. **IGFF will support the development of a real project pipeline drawing from six shortlisted priority technologies and applications:** (i) Round-the-Clock Renewable Energy (RTC-RE) with integrated storage, (ii) Compressed Biogas (CBG), (iii) Green Hydrogen, (iv) Electric Vehicles (EVs) and charging infrastructure, (v) Off-grid Solar Pumps, and (vi) Decentralized Renewable Energy (DRE) systems for rural applications. These technologies align with IGFF's four focus sectors—energy, industry, transportation, and agriculture and allied activities—and play a critical role in advancing India's clean energy transition. However, the actual project pipeline will be developed in close coordination with DFIs, ensuring that final project selections align with their sectoral priorities and financing strategies (for an example of an indicative project pipeline, refer to Appendix 4).

4.1 Round-the-clock renewables

73. **Round-the-Clock (RTC) renewables represent an innovative solution to address the intermittency of renewable energy by combining solar photovoltaic (PV) systems, wind farms, and energy storage solutions to provide a continuous and reliable power supply.** This hybrid approach ensures energy availability even when solar or wind generation fluctuates, integrating storage technologies such as lithium-ion batteries and pumped hydro to deliver stable, dispatchable power. For example, ReNew Power's RTC project integrates 400 MW of solar capacity, wind farms, and a battery facility capable of storing 100 MWh of electricity, ensuring 400 MW of uninterrupted power delivery.[111]

74. **This model not only enhances energy security and grid reliability but also reduces dependence on fossil fuels, helping to replace coal-based power plants and diesel generators, with offering other co-benefits.** For instance, ReNew Power's RTC project, with a total capacity of 966 MW, is expected to mitigate approximately 2.4 million tons of CO_2 annually. Additionally, RTC renewables improve resilience to climate variability, ensuring continuous energy supply for critical services during extreme weather events like heatwaves and floods. These systems are particularly valuable in regions with strong renewable potential but unreliable grid infrastructure.

[111] Round-the-clock (RTC) Renewable power project for Tata Steel

Beyond environmental benefits, RTC renewables contribute to job creation in manufacturing, installation, and maintenance while improving air quality by reducing reliance on polluting energy sources. They also support rural electrification, reduce dependence on diesel generators, and enhance the reliability of critical infrastructure during power outages, strengthening rural energy resilience.

75. **Recognizing the importance of RTC renewables, the Indian government has implemented several policies to promote their adoption.** For the procurement of RTC power from grid-connected renewable projects, the guidelines were issued in July 2020 and later amended in November 2020, February 2021 and February 2022. In June 2023, the Ministry of Power also issued guidelines for the procurement of firm and dispatchable power from grid-connected renewable energy projects with energy storage systems. These guidelines aim to enable discoms to procure FDE, coupled with energy storage, through tariff-based competitive bidding. They provide a framework for power purchase agreements for RTC supply, creating a structured approach for project development and implementation. The government has also set renewable purchase obligations (RPOs) targets for discoms to fulfil their RPOs not just by procuring standalone renewable energy, but also by using a mix of sources, including hybrid or RTC renewable options.

76. **The growing demand for RE capacity and storage systems, coupled with India's high solar and wind generation potential, increased policy support, and declining costs, presents a transformative opportunity for IGFF**. India's renewable energy market is projected to grow significantly, with installed capacity rising from 135 GW in December 2023 to 170 GW (excluding hydro) by 2025, in alignment with the government's ambitious target of 50 GW annual RE bidding announced in March 2023. However, due to intermittency issues, India's estimated solar power potential of 748,990 MW remains underutilized, which RTC projects can overcome.[112] RTC is gaining prominence, with over 16 GW already bid out and an additional 17 GW under consideration, contributing to an increase in the share of renewables in electricity generation from 23% in FY2024 to 40% by FY2030. Although the cost of hybrid or RTC power might appear high at present, standard solar and wind generation face significant fluctuations and variability in energy production. Concurrently, solar PV cell and module prices have fallen by 65% and 50%, respectively, over the past year, improving project financial viability and reducing the levelized cost of electricity. Innovations in battery storage technologies are further driving down costs, creating a compelling case for IGFF to support the scaling of RTC solar and storage solutions as a cornerstone of India's clean energy transition.

77. **RTC renewable energy offers a more reliable and cost-efficient alternative to standard-alone solar, wind, or conventional power sources, and are becoming more viable.** While the cost of hybrid or RTC renewable energy may seem high initially, standalone solar and wind power face significant fluctuations and variability in energy production, making them less reliable for consistent energy supply. Additionally, the per kWh transmission charges for standalone solar or wind projects significantly increase their overall cost. In comparison, RTC renewable energy, which integrates generation with storage and hybrid solutions, is proving to be a more feasible and reliable alternative, offering greater cost-efficiency and stability.[113] Hence, from an economic perspective, the viability of RTC solar is clear, assuming displaced thermal generation (valued at the marginal economic operating cost of coal-fired plant) and the avoidance of associated greenhouse gas emissions. (adopting an economic value of emissions of $56/ tCO2e as per ADB's guidance).[114] However, a strong financial case supporting uptake of RTC solar is still emerging: the capital and operating cost of energy storage facilities is still high relative to thermal electricity generating sources and the regulatory treatment of energy storage facilities in India remains unclear.

[112] Solar Overview | Ministry of New and Renewable Energy | India (mnre.gov.in)
[113] Ensuring Stable Supply: RTC renewables and FDRE's potential to address energy variability - Renewable Watch
[114] IGFF will adopt a flexible approach to pipeline development for RTC-renewables, tailoring project configurations based on the solar and wind potential of each proposed location. While some projects may integrate both solar and wind with battery storage, others may focus on either resource, depending on site-specific feasibility and energy demand profiles. However, the economic and financial viability assessments are modeled on an RTC-solar system with integrated battery storage, serving as a benchmark for evaluating project bankability.

78. **Despite its clear benefits and opportunities for supporting India's clean energy transition, RTC RE faces several barriers across technical, financial, and capacity dimensions**, as summarized below:

Technical	• **High capital costs:** Round-the-clock (RTC) solar projects face high upfront costs, including INR 4.5 crore/MW (USD 0.54 million) for solar and INR 8 crore/MW (USD 0.96 million) for battery storage, making them nearly twice as expensive as standalone solar installations.[115] This remains a deterrent for smaller developers. • **Grid integration challenges:** Existing grid infrastructure struggles to handle the variability and dispatchability of RTC systems, with inadequate transmission capabilities in many regions. Because of this, discoms after often forced to rely heavily on thermal power to meet peak demands. This also results in low compliance with renewable purchase obligation (RPO) targets. • **Technology maturity:** Although solar-wind-storage integration is advancing, concerns remain about the long-term reliability of these systems, especially in the context of India's diverse climatic conditions and evolving policy landscape.
Financial	• **High tariff rates:** Tariffs for RTC projects range between INR 4.0– INR 5.7 per unit, higher than standalone solar or wind projects (standalone costs for solar are in the range of INR 2.5 – INR 2.7 per KW). This reflects the additional costs of including energy storage and hybrid systems.[116] • **Access to financing:** High capital requirements and perceived risks make it challenging to secure financing. Many institutions lack familiarity with RTC models, creating hesitancy to provide loans. Further, the complexity of integrating renewable energy with storage raises risk premiums, leading to higher interest rates or reluctance to invest. • **Long payback periods:** Investors are discouraged by the lengthy payback periods, compounded by the historical payment delays of DISCOMs and further intensified by the volatility of electricity market prices.
Capacity-related	• **Limited expertise:** Financial institutions and public banks often lack technical expertise to evaluate RTC RE projects, resulting in missed financing opportunities.[117] • **Insufficient technology-specific training:** Comprehensive training programs for technicians, engineers, and financiers on RTC technologies remain limited. • **Awareness gaps:** Many stakeholders, including policymakers and investors, lack a clear understanding of RTC renewable's benefits, hindering adoption and implementation.

79. **IGFF can play a crucial role in reducing the offtake price of round-the-clock (RTC) electricity, making RTC-renewables more financially viable for developers**. By lowering costs, IGFF will expand the potential applications of this technology while addressing key barriers to its widespread adoption. To do so, the facility needs to consider the following targeted support:

- **Provide concessional finance**. IGFF can lower upfront costs through concessional loans, enabling developers to undertake high-capital RTC projects. Concessional capital provided through IGFF could reduce the WACC from 8.2% under DFI financing to 7.8%, making RTC-solar financing viable considering an FIRR of about 7.8% (ref. to Annex 3 for more details on the economic and financial viability.)

[115] Techno_Economic_Analysis_of_Renewable_Energy_Round_the_Clock_RE_RTC_Supply_for_Achieving_Indias_500_GW_Non_Fossil_Fuel_Based_Capacity_Target_by_2030
[116] OpenMedia
[117] Based on primary stakeholder consultations carried out as a part of this study.

- **Strengthen institutional capacity for lending.** The TA component can enhance the capacity of financial institutions to evaluate and structure RTC projects effectively. This includes training on project appraisal, climate risk assessments, and integrating hybrid solutions into existing infrastructure**.**
- **Drive policy and market innovations.** IGFF can advocate for regulatory reforms, such as long-term Power Purchase Agreements (PPAs) and enhanced grid integration policies, to create a more enabling environment for RTC solar. Supporting the development of hybrid wind-solar systems and innovative battery technologies can optimize energy generation and storage, further improving RTC solar's viability.

4.2 Compressed Biogas

80. **Compressed biogas (CBG) is produced through the anaerobic digestion of organic waste materials, converting them into renewable gas that can be used for cooking, heating, or as vehicle fuel.** Traditional biomass usage, particularly for cooking, is inefficient and harmful, causing respiratory illnesses among women and children. In 2020, around 54 per cent of bioenergy used was in the form of biomass for traditional cooking or heating.[118] CBG is a renewable energy source produced by purifying biogas derived from organic waste such as crop residue, cattle dung, sugarcane press mud, municipal wet waste, or effluents from sewage treatment plants. The purification process removes impurities like hydrogen sulfide, carbon dioxide, and water vapor, resulting in a gas with a methane content of over 90%. This purified biogas is then compressed to create CBG, which has properties similar to compressed natural gas (CNG).

81. **CBG systems not only mitigate greenhouse gas emissions but also contribute to energy security, reduced reliance on firewood, better air quality, and support rural incomes.** CBG significantly reduces methane emissions from landfills and agricultural waste management. Each ton of CBG generated has the potential to replace 1.38 kiloliters of gasoline, while simultaneously mitigating 27 tons of CO2 emissions through replacing gasoline and synthetic fertilizer (urea) by organic biogas slurry as by-product and preventing open dumping of organic waste.[119] The use of biogas for cooking and heating helps rural households transition away from traditional biomass fuels, reducing deforestation and enhancing resilience to climate impacts associated with reliance on unsustainable energy sources. CBG production creates jobs in waste management and biogas plant operations while improving air quality by reducing reliance on traditional fuels. Additionally, it supports rural economies by providing farmers with an additional income source through the sale of biogas and organic fertilizers.[120]

82. **In addition to multi-faced benefits of CBG adoption, its market potential also remains immense, with an estimated annual size of at least USD 1.5 billion, signaling significant opportunities for investment and expansion.[121]** The market for compressed biogas in India is poised for significant growth due to increasing energy demand and a strong push towards renewable energy sources. With an estimated production potential of nearly 62 million metric tons (MMT) of CBG and a bio-manure generation capacity of 370 MMT, India offers significant opportunities for scaling up, particularly in states like Uttar Pradesh (8,630 tons per day), Punjab, and Maharashtra.[122] Under the Government of India's Sustainable Alternative Towards Affordable Transportation (SATAT) initiative, the target is to establish 5,000 CBG plants by 2025. The 2023–24 Union Budget allocated ₹10,000 crores to promote 500 new CBG plants under the GOBARdhan scheme. Additionally, a 5% CBG blending mandate for organizations marketing natural gas and biogas, along with an excise duty waiver on CBG-CNG

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[118] Bioenergy for the Transition: Ensuring Sustainability and Overcoming Barriers (irena.org)
[119] Cost benefit and environmental impact assessment of compressed biogas (CBG) production from industrial, agricultural, and community organic waste from India | Biomass Conversion and Biorefinery
[120] GAIL and VERBIO India Partner to Advance Agricultural Residue-based CBG Projects
[121] Biogas: A possible solution for India's energy security and decarbonisation goals | IEEFA; Stakeholder interviews
[122] Centre for Science and Environment, Greening India's Energy Mix with Compressed Biogas (CBG), 2023

blends, underscores the government's commitment to the sector. Post the launch of the SATAT scheme, CBG infrastructure in the country has grown slowly from 9 operational plants[123] in 2021 to 82 operational plants in February 2025[124]. However, due to the government support and initiatives to develop the CBG ecosystem in the country, there is immense interest and traction from the developers to invest in CBG plants. As on July 2024, there were ~2000 active LoIs under SATAT initiative. These consist of large, medium and small-scale plants. The plant size and respective number of plants are summarized in the table below.

Table 6. Summary of LOIs under SATAT

Plant Size (CBG Production)	Number of CBG Plants
<2 TPD	**2**
2 TPD	**156**
>2-3 TPD	**132**
3 TPD	**48**
>3-4 TPD	**10**
4 TPD	**43**
>4-5 TPD	**53**
5 TPD	**251**
>5-8 TPD	243
>8-10 TPD	505
>10-15 TPD	433
>15-20 TPD	56
>20 TPD	50

83. **It is evident from the above table that more than one third of the potential market, based on active LoIs, is for CBG plants less than 5 TPD (inclusive).** These plants are typically classified as small scale plants and have a large investor base by MSME developers. Financial returns of such plants are typically subjected to sensitivity of financing variables such as high interest rates due to low security coverage by MSME's. Therefore, given a significant market for small scale CBG plants, appropriate financing mechanisms which aim to the address security coverage and low interest rate, would help boosting the development of CBG project pipeline in the country.

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123 Press Release:Press Information Bureau

124 GOBARdhan Unified Registration Portal

84. **The opportunity in the CBG sector is further underpinned by the compelling economic case driven by the dual benefits of avoided greenhouse gas emissions from decomposing biowaste and the displacement of imported fossil fuels such as LNG and LPG.** Project developers can generate financial returns through the sale of CBG to off-takers, priced competitively at the avoided cost of traditional fuels. However, financial viability remains constrained due to risks associated with fluctuating offtake prices, uncertain feedstock availability, and quantity variability, leading to high borrowing costs for developers and limiting scalability. Although CBG production technology is proven, its scalability has been limited by constrained investments, mainly due to concerns about feedstock availability and the resulting operational and financial sustainability. Given these constraints, each CBG plant's production remains small, and unit costs are high, impeding significant investments in the sector. To achieve cost reductions through economies of scale as the market expands, it is essential to resolve the fundamental bottleneck in the feedstock supply ecosystem.

85. **Despite the clear benefits, market and government impetus for the CBG sector, adoption faces significant hurdles in the country.** The past deployment trends of CBG plants in the India have been subjected to financial challenges by the lending institutions on providing debt to CBG developers. This has therefore plagued the potential growth of CBG plants, even though the country has immense feedstock potential. The following table outlines these challenges, focusing on key aspects like technology, waste type, project size, structures, offtakes, and developer profiles.

Technical	• **Feedstock availability:** The inconsistent availability of feedstock for biogas production poses a significant challenge. While India generates approximately 62 million tons of agricultural waste annually, only a fraction is utilized for biogas production due to inefficiency in processing, accompanied by logistical challenges in collection and transportation.[125] • **Technology adaptation:** Many existing biogas plants face operational inefficiencies due to outdated technologies that are not well-suited to local conditions or feedstock types. Adapting technology to local agricultural practices is essential for maximizing efficiency. • **Maintenance challenges:** There is often a lack of technical expertise in rural areas for maintaining biogas systems effectively. Regular maintenance is crucial to ensure optimal performance and longevity of the plants.
Financial	• **High initial investment costs:** The capital costs for establishing a biogas plant can range from INR 20-25 crore (~USD 2.3–2.9 million) for a 5 TPD plant, with 75-80% of it needed to meet its CAPEX requirements.[126] This continues to deter small-scale farmers from investing in this technology. • **Uncertain revenue streams:** Fluctuating energy prices create uncertainty regarding the profitability of biogas projects. Without stable pricing mechanisms or long-term contracts, securing financing becomes challenging.[127] • **Limited access to financing:** Many small-scale operators struggle to access loans due to perceived risks associated with biogas investment and lack of their own credit history. Traditional financial institutions may lack familiarity with technology and its potential returns.
Capacity-related	• **Weak Institutional support:** Local institutions may lack the capacity to support farmers in project development, financing, and regulatory compliance related to biogas projects. Even institutions with a priority lending mandate, such as NABARD, have indicated the need for enhanced support in this area.

[125] What do we do with India's mounting waste problem? | FairPlanet
[126] https://cdn.cseindia.org/attachments/0.11235300_1687759489_cse---overview-and-current-status-of--cbg-in-india.pdf
[127] Lack of market support for bio-manure hindering growth of compressed biogas plants

	• **Complex project structures:** CBG projects often involve multiple stakeholders (farmers, municipalities, technology providers, offtakers), requiring complex contractual arrangements. This complexity increases sensitivities to external factors and can deter financiers, especially those less familiar with the sector. • **Lack of awareness:** Farmers and potential investors often lack awareness about the benefits and viability of compressed biogas systems. This knowledge gap can hinder adoption rates.
Offtakes and market dynamics	• **Offtake uncertainty:** Securing long-term CBG offtake agreements is crucial for project viability. The nascent CBG market faces challenges related to pricing, demand fluctuations, and competition from other fuels. Distributing CBG via pipelines or bottling requires significant infrastructure investments, adding to the project cost and risk. The current offtake price mechanism needs strengthening to attract investor confidence. • **Limited market development:** The CBG market is still developing, and there is a lack of established trading platforms and price benchmarks. This lack of market transparency makes it difficult for investors to assess project risks and returns.
Developer profile	• **Limited access to affordable finance to small developers:** Small developers face significant challenges in accessing finance for CBG projects. They often lack the collateral required by traditional lenders and struggle to demonstrate project viability to investors. Many financial institutions remain cautious about lending, particularly to Micro, Small and Medium Enterprises (MSMEs) , due to their weak credit profiles. As a result, lenders impose high interest rates to mitigate credit risks and maintain financial margins, while also requiring substantial collateral to offset potential default risks. This leads to high-risk premiums for MSME borrowers, making CBG investments financially unviable. This persistent cycle of financial barriers has discouraged both investors and commercial financiers from scaling up the CBG sector. • RoI for CBG projects is deregulated, and hence MSME's typically face challenge in securing a low interest loan due to lack of providing security coverage.

86. **Role of MSME in the CBG sector development.** While the target under SATAT scheme is to establish 5,000 plants, public oil and gas companies received nearly 4,000 EOIs at their peak. However, as of February 2025, SATAT achieved only 82 operational CBG plants, and the number of active EOIs has nearly halved. Out of the ~ 2,000 active Letters of Intents (LOI) from private developers under the SATAT scheme, ~ 700 CBG projects are of small size in the range 2-5 TPD CBG production. These projects are typically developed by MSME applicants. The Government of India (GoI) defines the MSME as below: MSME developers play a critical role in the growth of India’s CBG sector.

Table 7 Classification of MSME

Classification	Micro	Small	Medium
Investment in Plant and Machinery or Equipment	not more than ₹ 1 crore	not more than ₹ 10 crores	not more than ₹ 50 crores
Annual Turnover	not more than ₹ 5 crores	not more than ₹ 50 crores	not more than ₹ 250 crores

87. **The projects being developed by MSMEs are essential for creating localized CBG supply chain, strengthening rural economies, and ensuring efficient waste utilization at the source. Unlike** large developers

who focus on centralized, high-capacity plants, MSMEs enable a distributed model of CBG production, making the sector more resilient and inclusive. Their success will drive wider adoption of CBG, enhance energy security, and accelerate India's transition to a circular economy.

88. **However, most of the MSMEs face significant challenges in accessing finance for CBG project investments.** Many financial institutions remain cautious about lending, particularly to MSMEs, due to their weak credit profiles. As a result, lenders impose high interest rates to mitigate credit risks and maintain financial margins, while also requiring substantial collateral to offset potential default risks. Even in cases where firm commitment on purchase of CBG by the OGMCs is established, there may still be security coverage to be provided by the developer to the bank to secure the loan. This leads to high-risk premiums for MSME borrowers, making CBG investments financially unviable. This persistent cycle of financial barriers has discouraged both investors and commercial financiers from scaling up the CBG sector. The following challenges faced by the MSMEs need to be addressed. By prioritizing MSMEs, we address the most underserved yet most impactful segment of the sector, ensuring that CBG development is inclusive, scalable, and sustainable across India.

- **High interest rates:** MSME developers in the CBG sector face high interest rates on loans due to their lack of creditworthiness, making debt financing expensive and financially unviable. CBG projects require substantial upfront capital investment, and the high cost of financing significantly impacts project viability. Unlike larger players who can secure lower-cost financing through banks or private equity, MSMEs rely heavily on bank loans, where interest rates can be as high as 12-14% for such projects
- **Limited financial incentives for PFIs:** Banks have limited financial incentives to lend to CBG projects, particularly those led by MSME players. CBG plants, especially small-scale ones, are perceived as high-risk ventures with uncertain cash flows, leading banks to prioritize lending to established industries with predictable returns. Additionally, the lack of dedicated financing schemes discourages banks from actively supporting MSME CBG developers, resulting in low credit availability for the sector.
- **Small developer size and collateral mismatch:** Given the perceived high-risks associated with CBG projects and MSME developers, banks often demand high collateral requirements, sometimes of minimum 50% of the loan amount. MSME developers, who typically operate with limited assets and weaker balance sheets, struggle to meet these stringent collateral conditions. This forces many promising small-scale developers to either delay or abandon their projects, as they are unable to secure the necessary debt financing.
- **Lack of awareness and technical capacity of PFIs:** A major challenge for MSME CBG developers is the lack of awareness and technical expertise among banks regarding the sector. Many financial institutions lack an in-depth understanding of CBG technology, feedstock economics, and revenue models, leading to conservative credit assessments and prolonged loan approval processes. Without proper capacity-building initiatives and sector-specific evaluation frameworks, banks remain hesitant to finance MSME-led CBG projects, further stifling sectoral growth.
- **Bureaucratic hurdles and permitting delays:** Obtaining necessary permits and approvals for CBG projects can be time-consuming and complex, adding to project costs and discouraging investors. Streamlining the regulatory process is crucial.

Some of the prominent banks' lending terms to CBG project are summarized as below.

<table>
<tr><th>Bank Name</th><th>Rate of Interest</th><th>Security Requirement</th></tr>
<tr><td>Punjab National Bank</td><td>MSME Based Advance: Linked with RLLR[128]
Others: Linked with 1 year MCLR
Concession of 0.25% on card rate is under this scheme.</td><td>Term Loan
Exclusive charge on entire projects assets including immovable assets, movable assets, cash flow, commercial agreement and Escrow accounts, DSRA
An escrow account shall be maintained by the Borrower in which all sale proceeds received from OMCs from sale of CBG will be credited. Payment will be made as per usual waterfall mechanism. The proceeds in the Escrow account shall be appropriated first towards Bank’s term loan repayment.
Working capital
Hypothecation of Stock & Receivables</td></tr>
<tr><td>Indian Bank[129]</td><td>Rate of Interest linked to MCLR.
Min ROI: MCLR (8.95%) + Spread (1.75%) = 10.70%
Max ROI: MCLR (8.95%) + Spread (4.50%) = 13.45%</td><td>The primary Security value of a minimum of 133% of the limit, including Hypothecation of stocks/book debts/machinery / EM of factory land & building/charge on assets created out of Bank finance.
Collateral security requirements are as below:
<table>
<tr><th>Types</th><th>Collateral Value</th></tr>
<tr><td>Wherever Commercial agreement is available</td><td>Nil</td></tr>
<tr><td>If Commercial agreement is not available.</td><td>Minimum 50% of the sanctioned limit to be obtained.</td></tr>
<tr><td>In case where mortgage ability of lease-hold land is not possible and without commercial agreement.</td><td>An equivalent amount of collateral to be obtained for the sanctioned limit.</td></tr>
<tr><td colspan="2">***Note: Wherever sufficient collateral is not available, the branch shall obtain Hybrid model security, by covering CGTMSE coverage up to ₹ 5.00 Cr. (Including-Convergence under AIF is eligible up to ₹ 2.00 Cr)</td></tr>
</table></td></tr>
</table>

[128] Repo linked lending rate

[129] Compressed Bio Gas plant financing under Sustainable alternative towards affordable Transportation – Indian Bank | Your Own Bank :: Financial services company

Bank Name	Rate of Interest	Security Requirement
Bank of Baroda[130]	• **Applicable rate of interest for accounts having aggregate limit up to Rs. 50 crores**: Rate of interest ranging from BRLLR+SP+0.50% to BRLLR+SP+5.40% based on internal credit rating and immovable property security coverage (including both primary and collateral immovable properties).[131] • **Applicable rate of interest for accounts having an aggregate limit above ₹ 50 crores and up to ₹ 100 crores**: The rate of interest shall be charged @1% over and above the rate of interest applicable to accounts having an aggregate limit up to ₹ 50 crores. • **Applicable rate of interest for accounts having an aggregate limit above Rs. 100 crores and up to Rs. 100 crores**: As per the classification of account vis. MSME/corporate advances.	• Exclusive charge over entire project assets including immovable assets and movable assets. • Hypothecation of stock and book debts. • Personal/corporate guarantee of proprietors/ Partners/ Promoters/ Directors/ Parent Company etc. • Charge over the Escrow Account in favor of the lenders. • Assignment or creation of charge on commercial agreement.
Canara Bank[132]	Depending upon borrower's credit rating. Competitive rate of interest is available on loans under the scheme on CBG plants	• Hypothecation of Assets created out of our finance. • Post development security (Prime Security) value of minimum 133% of the limit, including the mortgage of land where the CBG plant is established. Exclusive charge on entire project assets including immovable assets, movable assets, cash flow, Commercial Agreement and Escrow Accounts. • Commercial agreement executed by Oil & gas marketing companies with LOI holders which contains escrow account clause. No additional collateral to be insisted. Escrow Agreement shall be executed between LoI holder (CBG Plant) &

[130] Scheme for Financing Compressed Biogas (CBG) Plant in India | Bank of Baroda
[131] BRLLR is RBI repo rate plus the spread by the bank. SP is strategic premium.
[132] Compressed Biogas Plants

<table>
<tr><th>Bank Name</th><th>Rate of Interest</th><th>Security Requirement</th></tr>
<tr><td></td><td></td><td>Lender. Lending Bank Branch has to forward the copy of the Escrow agreement to OMCs and has to obtain the acknowledgement from OMCs.
• If Commercial agreement is not available collateral value of minimum 50% of sanctioned limit to be obtained.</td></tr>
<tr><td>Indian Overseas Bank[133]</td><td><table>
<tr><th>Particulars</th><th>Total Interest</th></tr>
<tr><td>Less than ₹ 1.00 Crore:</td><td>10.50%</td></tr>
<tr><td>Rating - IOB 1 & IOB 2</td><td>10.70%</td></tr>
<tr><td>Rating-IOB 3</td><td>10.95%</td></tr>
<tr><td>Rating-IOB 4</td><td>11.20%</td></tr>
<tr><td>Rating-IOB 5</td><td>11.80%</td></tr>
<tr><td>Rating-IOB 6 and above</td><td>12.30%</td></tr>
</table></td><td>• Prime security: Hypothecation of stocks / book debts / machineries / EM of factory land & building / charge on assets created out of Bank finance.
• Collateral: SARFAESI compliant Immovable property by way of EM of property & other tangible/liquid securities (MMD/FD/LIC policy etc.) belonging to the Borrower/ Guarantor with minimum 50% coverage.</td></tr>
</table>

89. **To tap this opportunity, IGFF would address high financing costs and limited access to capital in the CBG subsector by establishing a risk sharing facility, de-risking investments and improving the viability of CBG financing** (ref. to Annex 3 for more details on the economic and financial viability.) As demand for a consistent supply of feedstock grows, it is expected to spur innovation in feedstock collection and storage systems. This, in turn, will ensure a more reliable CBG supply, reducing risks for off-takers and enhancing financial viability across the entire CBG value chain. To achieve this, IGFF shall targeted support for CBG lending, such as:

- **Provide risk-sharing mechanisms.** Establish risk-sharing frameworks to attract private sector investment by reducing perceived financial risks. Blended finance options, combining grants with private capital, can make it easier for small operators to enter the market and scale operations sustainably.

- **Strengthening institutional capacity for lending and adoption.** Implement capacity-building programs to educate the on-lending banks on the technical and economic viability of biogas technology. Conduct awareness campaigns in rural communities to encourage integration of agricultural waste into the CBG supply chain, fostering local participation.

Risk Sharing Facility for CBG lending under IGFF

90. Under IGFF, ADB will establish a Risk Sharing Facility, supported by GCF's funding of $65 million for providing partial credit guarantees for MSME developers in the CBG sector. Managed by a DFI (likely NABARD and/or a subsidiary of NABARD), the RSF will provide Partial Credit Guarantees to Participating Financial Institutions (PFIs), covering up to 50% of potential defaults to incentivize lending for small-scale CBG projects.

[133] iob.in/resource/@@uploads/CEDocuments/@@uploads/CBG-under-SATAT

91. Despite high market potential, CBG project developers—particularly MSMEs—face significant financing barriers, including high interest rates (12–14%), limited credit access, and stringent collateral requirements. The RSF aims to de-risk lending by absorbing part of the default risk, enabling PFIs to expand their CBG loan portfolios while lowering financing costs for MSMEs.

92. The RSF is structured as a funded guarantee facility, providing coverage for newly originated PFI loans to MSMEs for CBG projects under the SATAT scheme. It will operate for 20 years, with PCGs issued during a 5 year period for a 12-year term per loan. The facility will initially have a 1:3 leverage ratio, with the potential to further increase to up to 1:5 or decrease to 1:2 based on portfolio performance.

93. The design of the RSF is such that it can tackle the following critical barriers facing the CBG sector:

- **Financial Viability**: High capital costs and uncertain revenue streams make CBG projects financially unviable. By offering PCGs, the RSF reduces financial institutions' perceived risks, enabling MSMEs to access affordable loans.
- **Feedstock Supply Chain**: The lack of efficient collection and handling systems for agricultural residues and municipal solid waste (MSW) hinders CBG production. The RSF incentivizes investments in supply chain infrastructure, ensuring a steady feedstock supply. Ensuring the right feedstock in terms of quantity, quality, and timing is critical. To address this, the project aims to promote feedstock trading systems through a mobile application, which has been successfully pilot-tested.
- **Institutional Fragmentation**: The CBG sector involves multiple stakeholders across agriculture, energy, and waste management. The RSF promotes collaboration among ministries, public sector undertakings, and private entities to streamline project implementation.
- **Stakeholder Awareness**: Limited understanding of CBG's benefits among financial institutions, farmers, and communities hinders adoption. The RSF supports capacity-building initiatives and public awareness campaigns to foster stakeholder engagement.

94. The RSF is designed to expand access to credit, mobilize private sector lending, and accelerate the development of a commercially viable CBG market, supporting India's transition to a circular, renewable energy-based economy. For more details on the RSF structuring and flow of funds, refer to Appendix 4.

4.3 Green Hydrogen

95. **Green hydrogen is produced using renewable energy sources through electrolysis, where water is split into hydrogen and oxygen using electricity generated from solar or wind power.** This clean fuel alternative has the potential to decarbonize various sectors including transportation, industry (especially steel production), and power generation, while also supporting the production of green ammonia for use in the agriculture sector. With India's ambitious goal of producing 5 million tons of green hydrogen annually by 2030 under the National Hydrogen Mission, this technology represents a significant opportunity for industrial decarbonization and economic development.

96. **Green hydrogen offers transformative benefits by driving industrial innovation, enhancing energy security, and supporting economic growth.** As a clean energy alternative, it can replace fossil fuels in hard-to-abate industries such as iron and steel, cement, and ammonia production, which collectively contributed approximately 28% of India's total emissions of 2,600 million metric tons (MMT) of CO2 in 2022.[134] Without targeted decarbonization efforts, emissions from these sectors are projected to increase by at least 2.6 times by 2050.[135] Green hydrogen not only helps reduce these emissions but also diversifies energy sources, decreasing

[134] ESSD - Global Carbon Budget 2022 (copernicus.org)
[135] MITJPSPGC_Rpt355.pdf

reliance on imported fossil fuels and bolstering resilience against global supply chain disruptions. Moreover, the green hydrogen industry is a catalyst for job creation and technological advancement. By 2030, initiatives under the National Green Hydrogen Mission are expected to generate nearly six lakh jobs. Over 66% of these jobs will emerge from renewable energy supply chains such as solar and wind for green hydrogen production, while plant construction and production activities will account for 22%. Electrolyser manufacturing and distribution will each contribute 4% of jobs, with storage solutions adding another 2%.[136]

97. **India presents a significant opportunity for green hydrogen investments, with demand projected to increase more than fourfold from 2020 to 2050, with 94% of this demand expected to be met by green hydrogen.** By 2030, industrial feedstock markets, including ammonia and refining, are anticipated to drive demand to 11 million tonnes per annum (MTPA), an 83% increase from current levels.[137] By 2050, green hydrogen demand is projected to exceed 27.2 MTPA, driven primarily by industries such as steel, fertilizers, refineries, and heavy-duty long-haul transportation.[138] The National Green Hydrogen Mission aims to develop at least 5 MMT of green hydrogen production capacity per annum by 2030. Achieving this will require capital expenditure of INR 8-9 trillion (USD 97.9-110 billion). This includes INR 5.5-6 trillion to establish 115-125 GW of renewable energy capacity to power hydrogen production, considering a plant load factor of 23-25%. The remaining INR 3-3.5 trillion is needed to build 35-40 GW of electrolyser capacity, with plant efficiency ranging from 75-80%.[139] The economic viability in green hydrogen production hinges on the cost of electricity, as it constitutes a substantial share of production costs. Currently, green hydrogen is economically competitive with grey hydrogen only when electricity used is either surplus or undervalued. However, policy measures such as waiving power banking and open access charges, reducing GST on electrolysers and renewable energy components, and providing incentives under schemes like SIGHT, coupled with market innovations in electrolysis and renewable technologies, can collectively reduce the levelized cost of green hydrogen by approximately USD 1.8 per kg in India.[140] These measures, alongside access to concessional finance and technological advancements, provide a robust pathway for scaling green hydrogen production, addressing industrial decarbonization, and positioning India as a global leader in the green hydrogen economy.

98. **However, given the early stage of green hydrogen technology both globally and in India, significant technical, financial, and capacity constraints must be addressed.** The key challenges include:

Technical	• **High production costs:** The current cost of producing green hydrogen remains high—around INR 250–525/kg (USD 3–6.5) — compared to grey hydrogen at INR 150/kg (USD 1.8/kg), due primarily to expensive electrolyser technology (costs ranging from USD 1,000- USD 3,000 per kW).[141] • **Infrastructure gaps:** There is limited infrastructure for hydrogen storage and distribution across India; developing this infrastructure will require significant investment and planning to match India's current ambitions and goals for the technology.[142] • **Technology maturity:** While electrolyser technology is improving rapidly, it is still relatively new in India compared to more established renewable technologies like solar PV or wind power. Given its early stage and high production costs, grey hydrogen remains the preferred input for chemical feedstock and/ or combustion fuel.[143]

[136] sscgj.in/wp-content/uploads/2023/05/Skills-Lanscape-for-Green-Jobs-Report.pdf
[137] Harnessing_Green_Hydrogen_V21_DIGITAL_29062022.pdf (niti.gov.in)
[138] How can India Boost Investment for Domestic Green Hydrogen?
[139] India will require INR 9 trillion capex to meet 2030 green hydrogen target – pv magazine India (pv-magazine-india.com)
[140] Ibid.
[141] How can India Boost Investment for Domestic Green Hydrogen?
[142] Harnessing_Green_Hydrogen_V21_DIGITAL_29062022.pdf
[143] Catalysing Green Hydrogen Growth in India | CEF Analysis (ceew.in)

Financial	• **Uncertain ROI:** The long payback periods associated with green hydrogen projects—often exceeding 10 years—can deter investment unless there are guaranteed off-take agreements or subsidies available. • **Market volatility:** Fluctuating prices for competing fossil fuels create uncertainty regarding the economic viability of green hydrogen as an alternative fuel source.[144] • **Limited access to capital:** Investors are hesitant to finance green hydrogen projects due to perceived risks associated with new technologies that lack proven track records in India.[145] • **Policy uncertainty:** While the National Green Hydrogen Mission provides a comprehensive framework, only a few states, such as Maharashtra and Uttar Pradesh, have developed dedicated policies for green hydrogen. This absence of localized policies hinders the ability to leverage regional strengths and resources effectively.
Capacity-related	• **Insufficient Research & Development (R&D):** Limited R&D funding specific to green hydrogen technologies hampers innovation necessary for cost reductions and efficiency improvements. • **Capacity among lenders:** Mainstream financial institutions currently do not have the capacity to evaluate green hydrogen projects, given their lack of experience and familiarity with the idiosyncrasies of these projects.[146] • **Lack of skilled workforce**: There is currently a shortage of skilled technicians trained specifically in hydrogen production technologies; building this workforce will require targeted educational programs.

99. **To address the challenges limiting green hydrogen investments in India, IGFF shall provide concessional capital to improve the financial viability of green hydrogen production by raising the maximum electricity purchase price at which it remains competitive.** Additionally, IGFF should also support DFIs in structuring viable financing models for green hydrogen projects, ensuring greater investment readiness and scalability. Key areas of support include:

- **Provide concessional capital and risk mitigation tools.** Deploy concessional capital, guarantees, and viability gap funding to lower the cost of capital, reduce financial risks, and make green hydrogen production cost competitive. Under the facility design, concessional capital is expected to bring down the WACC from 10.4% (current rates under DFI lending) to 9.3%, at which point the project shall become marginally viable considering a FIRR of 9.9% (ref. to Annex 3 for more details on the economic and financial viability.)
- **Support DFIs with project preparation and capacity building.** Invest in project preparation funding to develop a strong pipeline of bankable projects. Provide capacity-building initiatives to equip financial institutions and developers with the expertise needed to design, evaluate, and finance green hydrogen projects effectively.
- **Advocate for standardized offtake agreements upon DFI request:** Collaborate with the on-lending banks and other relevant stakeholders to develop standardized medium-term offtake agreements,

[144] Key Commodity Trends to Watch in 2025 | OilPrice.com
[145] How can India Boost Investment for Domestic Green Hydrogen?
[146] How can India Boost Investment for Domestic Green Hydrogen?

reducing revenue uncertainties for developers while ensuring pricing and volume flexibility for buyers. Advocate for a nodal agency to facilitate these agreements and support the sector's growth.

4.4 EV adoption and charging infrastructure

100. **Electric vehicles (EVs) utilize electricity instead of fossil fuels for propulsion, representing a significant shift towards sustainable transportation solutions that help reduce greenhouse gas emissions associated with conventional internal combustion engine vehicles (ICEVs).** The transition to EVs is supported by the development of robust charging infrastructure, which is essential for facilitating widespread adoption. In India, the government aims to achieve a target of 30% electric vehicle sales by 2030, which translates to approximately 10 million new EV registrations. The integration of charging stations into existing networks will be crucial for meeting this target and ensuring reliable access to charging facilities.

101. **The adoption of electric vehicles (EVs) and the development of supporting charging infrastructure offer transformative benefits for emissions reduction, air quality improvement, and energy security.** Ambitious electrification of the transport sector could reduce tailpipe emissions by 18% to 50% by 2040, depending on the pollutant. Even in a scenario where EVs are powered by coal and gas-dominated grids, their increased adoption would lead to net reductions in nitrogen oxides (NOx) and carbon dioxide (CO2), with only marginal increases in particulate matter (PM2.5) and sulfur dioxide (SO2), underscoring the positive impact of EVs on overall emissions.[147] In urban and peri-urban areas, where air pollution poses significant health risks, transitioning to EVs can dramatically lower harmful pollutants such as NOx and particulate matter. For instance, in New Delhi, the transport sector contributes 19%, 39%, and 81% of annual PM10, PM2.5, and NOx emissions, respectively.[148] A recent study by CSE found that vehicular emissions are the largest contributor to Delhi's air pollution, accounting for 51.5% of the city's pollution.[149] During the winter months, the practice of stubble burning in peri-urban and rural regions around the city exacerbates air pollution, leading to a severe public health crisis. The resulting smog severely impacts air quality, causing respiratory issues and reducing visibility, which in turn affects urban mobility and overall quality of life.[150] Electrifying transport can substantially reduce these emissions, improving air quality and public health. Beyond urban benefits, EVs expand affordable and clean transport access in underserved regions, enhancing mobility and equity. Moreover, the widespread deployment of EVs diversifies energy use in the transportation sector, reducing dependence on fossil fuels and strengthening national energy security. The growth of EV and charging infrastructure also drives economic benefits, creating jobs in manufacturing and installation, while fostering domestic innovation in clean transportation technologies.

102. **India's EV market is poised for exponential growth, offering significant opportunities for economic and environmental gains.** By 2030, EVs could account for up to 80% of all new two- and three-wheeler sales, representing an annual market opportunity of approximately INR 3.7 lakh crore (USD 44 billion).[151] In FY24 alone, EV sales exceeded 1.7 million vehicles, led predominantly by electric two-wheelers.[152] With ambitious targets under the FAME scheme—aiming for EVs to constitute 30% of all vehicle sales by 2030—India is on track to register around 10 million new EVs within the next decade. This growth is bolstered by proactive state and national policies, such as fiscal and non-fiscal incentives provided by 26 state and union territory governments, which have significantly reduced the total cost of EV ownership. Additionally, OEMs have committed over USD 6 billion to investments in EV-related technologies and manufacturing facilities, further accelerating market development.[153] Despite the significant growth in public charging infrastructure, increasing from 1,800 stations

[147] Understanding the emissions impacts of large-scale vehicle electrification in India
[148] AQM-SA_0.pdf
[149] source-contribution-and-congestion-impacts.pdf
[150] Explained: Why Delhi-NCR struggles with severe air pollution every winter | India News - Business Standard
[151] INDIA'S ELECTRIC MOBILITY TRANSFORMATION - RMI
[152] ARC FY2024 (jmkresearch.com)
[153] Electric Vehicle Industry in India: Investment Outlook and Market Profile (india-briefing.com)

in early 2022 to over 16,000 by March 2024, a considerable gap persists, with the current EV-to-charger ratio standing at 1:135. Achieving a globally competitive ratio 1:40 by 2030 will require the installation of over 400,000 chargers annually.[154]

103. **While the economic viability of EVs remains a challenge in the context of India's coal-dominant electricity grid, cost-competitiveness is already emerging for certain segments.** Financially, EVs offer compelling advantages for passengers and small-commercial applications due to lower operating costs, making them particularly viable for high-mileage commercial use. For two-wheel and three-wheel vehicles, the smaller cost premium for EVs over their ICE equivalents has now been reduced sufficiently to support economic viability in most cases. For four-wheel passenger EVs, economic viability improves significantly when charging is sourced from renewable energy (based on ADB analysis). This evolving landscape underscores the urgent need for focused investments in infrastructure, policy support, and technological advancements to realize the full potential of India's EV transition.

104. Current challenges to scale the adoption of EVs include:

Technical	• **Poor quality and spread of charging infrastructure:** The number of public EV charging stations in India doubled between 2023 and 2024, reaching a total of 12,146, with Maharashtra and Delhi leading this growth. Under the FAME II initiative, Gujarat and Kerala saw the highest number of commissioned stations.[155] However, 70% of these are in urban areas and their quality remains a concern, often due to the use of inappropriate base technologies and inadequate operations and maintenance (O&M). Publicly owned charging points are frequently cited for poor condition, while privately owned stations face low utilization rates of less than 10%, rendering them financially unviable without targeted support.[156] • **Range anxiety among consumers:** Close to 60% of all potential buyers in India remain hesitant due to concerns regarding limited driving ranges offered by current models available in the market.[157] The average range per charge often falls below acceptable levels desired by consumers seeking reliability during long-distance travel scenarios. • **Battery technology limitations:** Current lithium-ion batteries face challenges related to degradation over time, leading to reduced performance efficiency impacting overall user experience negatively. Ongoing research and development efforts are necessary to improve longevity while reducing costs associated with battery packs.
Financial	• **High upfront costs and interest rates:** The upfront cost of EVs is higher than comparable ICE vehicles, compounded by lower LTV ratios (10–30% lower) offered by financiers, resulting in higher down-payment requirements for buyers.[158] Interest rates for EV financing are 1–7% higher than for ICE vehicles, with the largest differences observed in the 2W segment, where NBFCs charge 2–7% more. Shorter loan tenors further add to the financial burden of smaller borrowers, including SMEs involved in manufacturing.[159] • **Limited affordable financing options for certain segments:** Many consumers and businesses seeking purchase loans for EVs or charging equipment face challenges due to a lack of attractive financing models tailored specifically for these investments. Limited affordable financing options hinder EV adoption, particularly for commercial 2Ws and 3Ws in peri-urban and rural areas, where perceived and actual default risks among borrowers often result in higher premiums.[160]

[154] The potential of EV infrastructure market in India - Forvis Mazars - India
[155] 12,146 public EV charging stations operational in India
[156] International Energy Economics and Finance (IEEFA). (2025). Upgrading India's public EV charging experience.

[157] The potential of EV infrastructure market in India - Forvis Mazars - India
[158] ADB-EV-Financing-Report_VS_compressed.pdf
[159] Ibid.
[160] ADB-EV-Financing-Report_VS_compressed.pdf

	• **High perceived risks and uncertainty among financiers:** Financiers perceive high risks of product failure due to the absence of certification frameworks guaranteeing EV performance and the proliferation of less-established OEMs in the 2W and 3W markets, making product credibility hard to assess. Further, limited evidence on long-term performance and efficiencies across the product lifecycles create uncertainty for financiers about the asset value recovery in cases of loan default.[161]
Capacity-related	• **Limited capacity to assess financing risks:** Public banks and PSUs often lack the technical expertise and frameworks necessary to evaluate the financial risks associated with emerging technologies like electric vehicles.[162] This gap in capacity results in hesitancy to provide loans for EV projects, particularly in less-established markets or for newer technologies such as advanced batteries. • **Need for specialized training and expertise:** There is a significant need for tailored training programs for financial institutions to better understand the unique operational and maintenance requirements of EV projects. Such training would enable lenders to assess project viability more effectively and provide targeted financial solutions. • **Insufficient consumer awareness initiatives:** A lack of widespread, coordinated public awareness campaigns on the economic, environmental, and operational benefits of electric vehicles has hindered consumer adoption.[163] Educating the public about the long-term value and cost savings of EVs is critical to increasing market demand and supporting financing flows.

105. **To effectively support the e-mobility transition, interventions must focus on improving access to tailored financing solutions for this fast-growing market segment.** This includes offering financing products with longer loan tenures and reduced equity requirements (higher loan-to-value ratios), designed to accelerate the adoption of EVs by reducing upfront costs and making the shift from ICE vehicles more financially viable. Additionally, targeted support for the expansion of charging infrastructure will strengthen the overall financial case for transitioning to EVs by addressing one of the most critical barriers to widespread adoption, especially in peri-urban and rural context, where the adoption rates for EVs are limited despite a growing demand.[164]

106. **To support further deployment of EV and charging infrastructure, IGFF could consider adopting a flexible approach to resource allocation.** This flexibility should extend across vehicle types, including two-wheelers, passenger cars, and buses, as well as financing structures, such as OEM financing packages, finance leases, and direct loans. Moreover, a portion of IGFF's resources should be directed toward scaling charging infrastructure to ensure the ecosystem can sustain the projected growth in EV adoption. This adaptable strategy will enable IGFF to remain responsive to market dynamics while effectively supporting the transition to clean transportation. The following are the interventions IGFF will undertake to support the development and deployment EV and charging infrastructure:

- **Provide concessional financing:** The IGFF can address the high upfront costs of EV production and infrastructure development by offering concessional loans for DFIs to reduce the WACC of borrowing, ultimately bringing down the total cost for the end-consumer. This can reduce financial risks for developers and manufacturers, enabling the deployment of high-capital EV projects and promoting affordable financing for end-users, particularly for 2- and 3- wheeler segments in peri-urban and rural regions given its high economic and financial viability. E-mobility exhibits strong financial and economic

[161] Innovative Financing Models for India's EV Charging Infrastructure - Bolt Earth
[162] mobilising_finance_for_evs_in_india_compressed-1-10.pdf
[163] Barriers to the Adoption of Electric Vehicles: Evidence from India | Barriers to the Adoption of Electric Vehicles: Evidence from India
[164] Faster adoption of electric vehicles in India.pdf

viability, with an EIRR of 15.3% and FIRR of 19.3%, well above the WACC of 10.2% under DFI financing. (ref. to Annex 3 for more details on the economic and financial viability.)

- **Accelerate charging infrastructure expansion:** Targeted support through grants, viability gap funding, or low-interest loans can be directed toward expanding public and private charging infrastructure. This includes prioritizing rural and semi-urban areas to enable higher adoption in these regions, while also addressing operational challenges, such as maintenance and utilization rates, to improve the reliability and financial viability of charging networks.
- **Strengthen institutional and financial capacity:** IGFF can enhance the capacity of financial institutions and public sector undertakings (PSUs) to evaluate and manage risks associated with EV projects. Technical assistance programs can focus on training financial institutions in project appraisal, climate risk assessments, and emerging financing models, such as EV-specific lease structures and OEM-backed loans.
- **Facilitate policy and regulatory alignment:** By working closely with policymakers, IGFF can advocate for incentives and regulatory frameworks that encourage EV adoption. This includes promoting favourable policies like lower GST rates for EV components, standardization of medium-term offtake agreements for EV fleets, and supporting grid upgrades to enable efficient integration of EV charging demands.

4.5 Off-grid solar irrigation pumps

107. **Off-grid solar water pumps harness solar energy to provide irrigation solutions without relying on grid electricity, which is particularly crucial for rural agriculture where grid access is limited or unreliable.** These systems consist of solar photovoltaic (PV) panels connected to a pump that draws water from underground or surface sources for irrigation. A typical off-grid solar water pump system, ranging from 1 HP to 10 HP, can meet the irrigation needs of small to medium-sized farms. These pumps significantly lower operational costs by eliminating the reliance on diesel fuel, while also reducing greenhouse gas emissions. By improving irrigation access, particularly for small and marginal farmers—who comprise 86% of India's farming population—solar pumps offer a sustainable solution for enhancing agricultural productivity in rainfed and drought-prone regions.

108. **Solar water pumps are seen by the Indian government as a practical step toward energy independence.** A number of initiatives have been started to promote their widespread adoption. One of the flagship schemes is the PM-KUSUM effort that aims to encourage the use of solar energy in agriculture through the installation of irrigation solar pumps. With an ambition to distribute about 1.35 million independent solar pumps and about 3.55 million grid connected solar pumps and feeders up to March 2026, this scheme is expected to create an expected more than 15 GW of solar capacity and provide irrigation to over 2.75 million hectares of farmland.

109. **Off-grid solar water pumps offer significant environmental, economic, and social benefits, making them a transformative solution for sustainable agriculture.** By replacing diesel-powered irrigation pumps—which emit approximately 2.7 kg of CO_2 per liter of diesel consumed—solar pumps drastically reduce greenhouse gas emissions and black carbon emissions, which have quadrupled in the Indo-Gangetic Plain region between the late 1980s and 2013-14.[165] These systems enhance climate resilience by providing a reliable water supply during dry spells and droughts, ensuring consistent crop yields and bolstering food security amid increasing climate variability. Additionally, solar pumps improve air quality, lower operational costs for farmers by reducing dependency on expensive fossil fuels and create employment opportunities in installation and maintenance. While increasing access to water for small and marginal farmers, especially in areas with underserved irrigation

[165] Ppt_SRawat.pdf

infrastructure, these benefits must be paired with demand-side interventions that promote water efficiency to ensure the long-term sustainability of water resources.[166] Together, off-grid solar water pumps represent a critical step toward energy independence in agrarian regions, stabilizing farmers' incomes, adoption of sustainable agriculture practices, and a low-carbon future.

110. **While off-grid solar water pumps present transformative opportunities for sustainable agriculture and climate resilience, their widespread adoption is hindered by several technical, financial, and capacity-related challenges.** Addressing these barriers is critical to unlocking the full potential of this technology, particularly for small and marginal farmers in rural areas.

Technical	• **Variability in solar resource availability:** The efficiency of solar water pumps depends heavily on sunlight availability, which is often inconsistent during monsoon seasons or extended cloudy periods. This variability can disrupt irrigation schedules, particularly in regions reliant on seasonal farming cycles. • **Infrastructure limitations and under-utilization factors:** While solar water pumps are being installed, their effectiveness is often reduced by the lack of adequate water distribution systems, such as pipelines and reservoirs. This makes it challenging to deliver water to distant or larger fields. There is also the challenge that solar pumps are often underutilized, as they are only used during single crop harvests annually, leaving energy unutilized during off-seasons and affecting economic viability. This demonstrates the need for innovations that integrate the application with battery storage technologies for increased utilization of the energy generated. • **Maintenance and reliability issues:** Rural areas often lack access to skilled technicians for the maintenance and repair of solar pump systems. This can lead to prolonged downtimes and reduced reliability, undermining farmers' trust in the technology. Despite government-mandated five-year service warranties, delays in repairs can affect crop productivity and farmers' ability to repay loans.[167]
Financial	• **High upfront costs despite subsidies:** The high upfront cost of solar-powered pumps, averaging INR 1.7 lakh for a 3 HP system, remains a significant barrier despite 30–50% subsidies provided by central and state governments. Farmers must still finance the remaining amount, which remains considerably high for small and marginal farmers. For example, under the PM-KUSUM scheme, which subsidizes the installation of 14 lakh standalone solar agriculture pumps (under Component B), only 30% of the target has been met due to the high equity requirements from farmers.[168] • **Limited access to low-cost financing:** Many smallholders' farmers struggle to secure loans due to high interest rates, which are in the range of 12-14% and strict collateral requirements, limiting access to formal financing options. For these reasons, many small farmers would still need to rely on informal loans with higher interest rates to make the equity investment for pumps, further pushing them into debt traps.[169] • **Low ticket size and perceived risks:** Perceived risks around the performance and reliability of off-grid solar pumps deter financiers. High transaction costs for processing and managing loans for such pump systems further reduce their attractiveness to lenders.[170]

[166] They constitute close to 80 percent of all farmers, with their population widening; two thirds of them still rely on diesel/kerosene-powered pumps. How can India Scale Up Solar Pumps & Make Farms Diesel Free by 2024? (ceew.in)
[167] CEEW-Financing-Solar-for-Irrigation-SPIS-17Jan18_1.pdf
[168] Under-utilisation of standalone solar pumps remains a challenge
[169] Indias-Vast-Potential-in-Solar-Powered-Irrigation-.pdf
[170] irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Solar_Pumping_for_Irrigation_2016.pdf

Capacity-related	• **Limited understanding among FIs:** Public banks and PSUs often lack the expertise needed to assess the viability and risks associated with financing off-grid solar pump projects, leading to hesitance in lending.[171] • **Insufficient training for loan officers:** There is a need for training programs focused on educating bank officials about renewable energy technologies, including off-grid solar systems, to improve their ability to evaluate loan applications effectively. • **Weak institutional support for project development:** Financial institutions may lack the necessary support structures to assist farmers in navigating regulatory requirements and project development processes related to solar pump installations.

111. **The market for off-grid solar water pumps in India presents a significant growth opportunity, driven by rising agricultural demand and supportive government initiatives.** As of January 2025, approximately 300,000 solar water pumps are operational, a small fraction of the estimated potential market. With over 5 million additional installations needed by 2030 under government schemes, there is substantial scope for scaling production and deployment. The PM-KUSUM scheme provides financial incentives, creating a conducive environment for investments in off-grid solar technologies and encouraging farmers to transition from traditional irrigation methods. The total addressable market for solar water pumps is valued at ~USD 6.4 billion, benefiting 7.5 million marginal farmers. This could increase to USD 7.7 billion if animal husbandry applications are included. Within this, the serviceable market for irrigation alone is projected to reach USD 2.7 billion by 2026.[172] Solar water pumps also align with India's sustainability goals by reducing reliance on fossil fuels and enabling farmers to irrigate efficiently in remote areas without grid access.

112. **Replacing isolated diesel-powered pumps with direct current (DC) solar pumps offers robust financial and economic returns, making this technology highly feasible.** Solar pumps, while having higher upfront costs, benefit from significantly lower operating expenses compared to diesel-powered alternatives. Farmers using low-quality diesel generators often face high running costs, making solar solutions a cost-effective alternative in the long term. The economic rate of return for this subproject is high even without factoring in avoided greenhouse gas emissions, and the financial returns to farmers are compelling when compared to continued reliance on diesel generators. Moreover, the facility's provision of concessional loans or subsidies can overcome the capital cost barrier, enabling wider adoption among small and marginal farmers. These factors, coupled with the substantial savings on diesel fuel and maintenance, demonstrate the viability of scaling solar water pump deployment as a transformative solution for India's agricultural sector.

113. **To address the challenges and capitalize on the opportunities identified, IGFF should focus on a multi-pronged approach that aligns with the barriers faced relating to its adoption.** For this, IGFF must consider the following interventions:

- **Provide concessional loans:** Off-grid solar pumps show the highest financial returns of the modelled investment portfolio, with an FIRR of 46.0%, significantly above the WACC of 15.6% under standard DFI financing. Concessional support lowers the WACC to 14.2% (ref. to Annex 3 for more details on the economic and financial viability.) Through concessional capital, the facility can lower the upfront costs for farmers through concessional loans and viability gap funding, making solar water pump systems

[171] World Bank Document
[172] Mainstreaming Micro Solar Pumps to Improve Incomes of Marginal Farmers | CEEW

more accessible to small and marginal farmers. This will directly contribute to greater uptake of the PM-KUSUM scheme.

- **Aggregate projects to increase attractiveness:** Smaller, individual projects can be aggregated into larger portfolios to increase the ticket size, making them more attractive to investors. This approach also reduces transaction costs and improves access to capital from private and institutional financiers.
- **Strengthen the capacity of FIs to understand on-ground needs while designing loan products:** Strengthen the capacity of local institutions such as NABARD to provide streamlined support for farmers, including assistance with project financing, regulatory compliance, and integration of solar technology with existing irrigation systems.

4.6 DRE systems to power rural applications

114. ***DRE* systems are pivotal in achieving universal rural energy access, fostering a just and inclusive energy transition, and meeting India's climate and developmental objectives.** The DRE livelihood applications are those applications that are powered by renewable energy – solar, wind, micro-hydro, biomass – and their combinations that are used for earning livelihoods directly such as solar dryers, solar mills, solar or biomass powered cold storage/chiller, solar charkha and looms, small-scale biomass pellet-making machines. Traditionally used to provide basic services like lighting, DRE systems are now emerging as viable alternatives to centralized power generation due to their environmental benefits, cost-effectiveness, lower risks, and reliability.[173] These systems leverage local resources and provide the option of tailoring it to meet the specific requirements for residential, productive use, and institutional applications.[174] In India, the top five farm-based livelihood appliances are the solar water pumps, solar refrigerators and freezers, solar mills/rice Huller and polisher, solar cold storage devices and solar dryer.

115. **By improving access to reliable and clean energy, DRE systems not only enhance quality of life but also contribute to climate mitigation, adaptation, and broader socio-economic resilience.** They enable income-generating activities, provide reliable energy for critical services such as healthcare and education, and support sustainable development in rural areas with low population density, where they offer a fast and cost-effective solution for increasing electricity access.[175] DRE systems mitigate greenhouse gas emissions by displacing fossil fuel use for powering various agriculture and related activities, such as the powering of dairy sectors and flour mills, reducing CO_2 and methane emissions for the agriculture and allied sectors. Adaptation benefits include greater community resilience to climate variability, with reliable energy supply supporting cold storage to prevent food spoilage and ensuring uninterrupted healthcare services during extreme weather events. They are particularly attractive in rural areas with low population density, where they offer a fast and cost-effective solution to increasing electricity access while improving livelihood security.[176] In 2021 alone, 179 million people gained access to electricity through DRE solutions, up from 35 million in 2012—a fivefold increase, demonstrating their increasing uptake among underserved sections of the economy.[177]

116. **India has a significant opportunity to create a USD 50 billion market for new livelihood applications in rural settings.**[178] DRE-powered rural applications, which include solar-powered looms and chakras, cold storage, dryers, and vertical fodder grow units, are already making a substantial impact at scale[179] and have the potential for further impact across the country. A study by CEEW identified twelve mature DRE livelihood technologies that are collectively capable of benefiting 37 million livelihoods and generating a revenue

[173] Power to the people: Local community initiatives and the transition to sustainable energy - ScienceDirect
[174] doc2023720226501.pdf (pib.gov.in)
[175] Fostering Livelihoods with Decentralised Renewable Energy: An Ecosystems Approach (irena.org)
[176] SELCO Foundation and IRENA, Fostering Livelihoods with Decentralised Renewable Energy: An Ecosystems Approach, 2022; Decentralised solar setups give power access to small farmers, facilitate innovations
[177] How can Global Good Practices Mainstream DRE Solutions for SDG7? (ceew.in)
[178] doc2023720226501.pdf (pib.gov.in)
[179] SELCO-Foundation- 175-Sustainable-Energy-Driven-Livelihood-Applications-2023_compressed-1.pdf (selcofoundation.org)

opportunity worth USD 48 billion for enterprises deploying and commercializing such technologies. The study goes on to state that over a 15-year investment horizon, *the* DRE variants become more attractive than their grid alternatives. Geographically, the greatest impact opportunity lies in states including Uttar Pradesh, West Bengal, Bihar, Gujarat, Maharashtra, Madhya Pradesh, and Karnataka, given their rural population size. In terms of the technologies themselves, solar-powered pumps, including both higher capacity and micro-pumps, have the highest deployment potential. They are followed by solar-powered vertical fodder growing units and solar dryers. Together, these four technologies have the potential to impact approximately 27 million livelihoods.[180] Beyond the well-established applications, such as solar rooftop and off-grid solar for agricultural pumps and cold storage, new downstream use cases for DRE are emerging. These include energy storage, EV charging, and various rural non-farm productive use applications. Estimates indicate that India needs to increase its annual investments in DRE by at least tenfold from 2018 levels to reach USD 18 billion to meet its sustainable energy targets for this decade, demonstrating the market opportunity and the impact potential of investing in DRE systems.[181]

117. **Despite their transformative potential, scaling DRE systems for livelihood applications faces significant technical, financial, and capacity-related barriers that hinder widespread adoption and impact.** Some of the key challenges are summarized below:

Technical	• **Fragmented industry and lack of standardization:** The DRE sector in India remains highly fragmented, with only a few players operating at a pan-India scale. These players are often backed by Indian corporate or foreign private capital, while most of the market comprises small local installers who primarily execute work orders for larger firms. This fragmentation leads to inconsistent quality and lack of standardized solutions tailored for diverse agricultural applications, such as dairy farms, flour mills, and cold storage facilities. • **Challenges in consistent energy supply and maintenance:** Operational risks related to maintaining consistent energy supply and addressing maintenance needs present significant hurdles. Rural areas often lack access to skilled technicians capable of installing and maintaining DRE systems, leading to frequent downtimes.[182] These issues deter lenders by complicating the evaluation of project feasibility and sustainability, particularly for remote applications where technical support infrastructure is weak. • **Integration with existing equipment.** Integrating DRE systems with existing agricultural equipment, such as irrigation systems or cold storage units, poses technical challenges. Many of these systems require specialized knowledge to ensure compatibility and seamless operation, which is often unavailable in rural settings.
Financial	• **High capital costs and limited access to affordable finance:** DRE technologies for livelihood applications, such as solar PV systems for dairy farms, involve significant upfront costs, often to the tune of INR 3.5 crore (USD 0.4 million) per 700 kW system. Despite the availability of government subsidies, these costs remain prohibitive for many small-scale operators who often need to prioritize existing operational costs cover capital expenses that come with installation of new technologies. Moreover, traditional financial institutions focus primarily on conventional DRE technologies, such as solar lanterns and pumps, neglecting the financing needs of more innovative and capital-intensive livelihood applications, such as for dairy farms and flour mills.[183] • **Perceived risks and profitability concerns:** Financiers perceive rural DRE projects as high-risk due to limited credit histories and financial records of smallholder farmers and micro-enterprises. The low confidence in the profitability of DRE applications for

[180] Decentralised-Renewable-Energy-Technologies-Market-Impact-Potential-For-Sustainable-Livelihoods.pdf (ceew.in)
[181] The-Future-of-Distributed-Renewable-Energy-in-India.pdf (climatepolicyinitiative.org)
[182] Distributed Renewable Energy (DRE) can expand energy access in rural India | Global Energy Alliance for People and Planet
[183] 1645592374-CLEAN Network, CEEW_State-of-the-Decentralized-Renewable-Energy-Sector-in-India_Feb 2022.pdf

	productive use further discourages investment.[184] High interest rates and short repayment terms often render loans unaffordable, while limited awareness among financial institutions about the potential of DRE systems adds to this challenge. • **Gendered barriers to finance:** Women-owned enterprises face disproportionate difficulties in accessing credit compared to their male counterparts. This restricts their ability to invest in productive DRE technologies, perpetuating gender disparities in energy access and economic participation.[185]
Capacity-related	• **Weak institutional capacity and support for project development:** Rural financial institutions and microfinance bodies often lack the capacity to support farmers and small enterprises with project development, financing, and compliance for DRE installations. Without targeted capacity-building efforts, this barrier further hinders the adoption and scaling of DRE technologies for livelihood applications. • **Limited awareness and expertise among end-borrowers:** Many rural farmers and microfinance institutions lack awareness about the benefits and operational requirements of DRE systems.[186] This gap limits the development of robust project pipelines and constrains financial institutions from effectively investing in the sector.

118. **The economic and financial viability for acting upon these opportunities is driven primarily by the ability of DRE systems to displace electricity sourced from thermal power plants, thereby avoiding fuel and emissions costs.** Economically, the benefits are substantial when factoring in avoided emissions based on India's weighted average emission factor. Financially, the viability for plant owners lies in the reduced cost of electricity purchases, as DRE systems offset a significant portion of grid-based electricity consumption. While grid connections will remain in place, avoiding demand or capacity charges, the IGFF could play a pivotal role in enhancing financial viability by lowering the weighted average cost of capital for project proponents. This enables investments in DRE systems to align with the financial realities of commercial electricity tariffs, ensuring both economic efficiency and broader adoption of clean energy solutions.

119. By addressing existing barriers through targeted interventions, IGFF can help India unlock the full potential of these technologies, integrating them into a broader clean energy strategy that also advances rural development and climate resilience. To support India in achieving this transformational shift, IGFF should consider the following strategic interventions:

- **Provide concessional financing and bundle individual projects.** Offer concessional loans tailored to different DRE applications, such as solar-powered cold storage or biogas systems for dairy farms, to reduce high upfront capital costs. Given that financial viability remains challenging under DFI financing alone (FIRR of 9.1% vs. WACC of 10.1%), IGFF's concessional support would lower the WACC to 9.1%, making projects marginally viable (ref. to Annex 3 for more details on the economic and financial viability.) To further enhance investment attractiveness, bundle smaller DRE projects into larger, aggregated portfolios, reduce transaction costs, increase ticket sizes, and make them more appealing to institutional investors.
- **Build FI capacity for project development and evaluation.** Develop targeted training modules for banks and microfinance institutions on evaluating the viability of DRE projects, including understanding specific technologies like solar-powered irrigation systems and productive-use appliances.
- **Promote innovation in business models.** Support entrepreneurs in developing commercially viable models, such as pay-as-you-go (PAYG) or lease-to-own schemes, to make DRE systems accessible to

[184] Shakti Energy Foundation and Clean Energy Access Network, State of the Decentralized Renewable Energy Sector in India, 2019.
[185] irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jan/IRENA_Livelihood_Decentralised_Renewables_2022.pdf?rev=7f7ca5cd9eea443483dea7987ef952e9
[186] ceew.in/sites/default/files/how-decentralised-renewable-energy-powered-technologies-impact-sustainable-livelihoods.pdf

low-income users. Encourage partnerships between private sector players and local cooperatives to scale adoption, leveraging community networks for last-mile delivery and financing.

4.7 Summary of the technologies and solutions offered by IGFF

120. The following table summarizes the six technologies, listing their contribution to the clean energy transition, adaptation and development co-benefits, current barriers to their deployment, and the solutions offered by IGFF to overcome them.

Technology description	Contribution to Clean Energy Transition	Adaptation & development co-benefits	Barriers			Solutions Offered by IGFF
			Technical	Financial	Capacity	
RTC renewables integrate solar, wind, and battery storage to provide continuous and dispatchable clean power, addressing intermittency issues in renewable energy generation.	Provides stable, dispatchable clean power, reducing reliance on coal-based generation and enhancing grid reliability for renewables.	Enhances energy resilience, supports rural electrification, and creates jobs in the renewable energy sector.	• High capital costs for hybrid RE systems • VRE-grid integration challenges • Concerns regarding the long-term performance sustainability of RTC technologies	• High upfront costs and long payback periods • Higher tariffs for RTC power compared to stand-alone installations • Investor risk perceptions driven by DISCOMs' history of under - performance	• Limited expertise among financial institutions to evaluate and structure RTC-RE finance • Limited awareness and capacity training on hybrid RE integration	• Provides concessional finance to improve the bankability of RTC renewables • Strengthens DFIs capacity to assess and structure hybrid RE financing Promotes standardized risk-assessment frameworks for RTC projects
Compressed Biogas (CBG) is derived from organic waste through anaerobic digestion, purified to produce a high-methane content fuel that can replace fossil fuels in various applications.	Converts waste into a clean energy source, reducing methane emissions and replacing fossil fuels in transportation and industry.	Reduces indoor air pollution, improves rural energy security, and provides additional income sources for farmers.	• Unreliable feedstock supply • Concerns over operational inefficiencies from outdated biogas technology • Maintenance challenges in rural areas	• High CAPEX requirements • Uncertain revenue streams due to feedstock variability and fluctuating offtake prices • Limited financing options for small-scale developers	• Weak institutional support for small developers • Complex project structuring that requires multiple stakeholders across the value chain	• Establishes a risk-sharing facility to provide credit guarantees • Provides capacity-building for DFIs, PFIs and MSME developers
Green hydrogen is produced using renewable electricity to split water into hydrogen and oxygen, serving as a clean alternative for industry, transport, and power generation.	Decarbonizes hard-to-abate industries such as steel and cement; reduces dependency on imported fossil fuels.	Strengthens industrial energy security, creates jobs in electrolyzer manufacturing, and supports domestic green	• High production costs • Insufficient hydrogen storage and transport infrastructure • Limited large-scale	• Uncertain revenue models • High initial investment costs • Limited commercial-scale	• Financial sector is largely unfamiliar with hydrogen projects • Related to above, lack of technical capacity to	• Deploys concessional capital to de-risk early-stage green hydrogen projects • Supports hydrogen finance structuring through

		hydrogen production.	deployments with most in R&D/ pilot stages	hydrogen financing • Limited investor confidence despite a national policy given its early stages of adoption at state-levels	evaluate and structure green hydrogen finance products	capacity building • Supports knowledge exchange on hydrogen incentives, subsidies and pricing • Facilitates pilot-to-scale financing models for hydrogen project bankability
Electric Vehicles (EVs) rely on electricity rather than fossil fuels, reducing emissions and improving urban air quality; requires widespread **charging infrastructure** to scale adoption.	Electrifies transport, reducing dependence on fossil fuels and cutting emissions from internal combustion engines.	Improves urban air quality, supports clean mobility, and reduces fuel import dependency.	• Poor quality and limited deployment of charging infrastructure • Concerns on life-time performance on batteries • Range anxiety among customers for long-distance travel	• High vehicle purchase costs • Higher interest rates on EV loans • Lack of financing options for commercial 2Ws and 3Ws in peri-urban and rural settings with high premiums	• Limited capacity among financial institutions to assess EV project risks • Insufficient awareness of the long-term benefits among customers limiting uptake	• Provides concessional loans for EV adoption • Expands financing options for charging infrastructure • Facilitates tailored loan structures
Off-grid solar water pumps use solar PV to provide irrigation without relying on grid electricity, reducing diesel dependency and ensuring reliable water access for farmers.	Replaces diesel-powered pumps, lowering carbon emissions while ensuring sustainable irrigation for farmers.	Improves access to irrigation for small farmers, stabilizing incomes and strengthening rural resilience.	• Variability in solar and wind resource availability • Under-utilization challenges • Maintenance gaps in rural areas	• High initial investment despite subsidies • Limited availability of low-cost financing options for smallholder farmers	• Limited awareness among farmers on financing options • Need for institutional support in scaling solar irrigation	• Extends concessional loans for solar pump adoption • Promote group financing models for PDFI on-lending, enabling farmer cooperatives and FPOs to collectively secure funding for shared solar pump usage
Decentralized Renewable Energy (DRE) systems power rural livelihood applications such as solar-powered cold storage, irrigation, and small-scale processing units to	Expands renewable energy access in underserved areas, reducing reliance on diesel and improving rural electrification.	Supports agricultural productivity, enhances rural resilience, and improves food security.	• High installation costs • Lack of local operational and servicing expertise • Fragmented value chains	• Limited tailored financial products for rural enterprises • High upfront costs and lack of credit	• Lack of technical know-how among rural businesses • Absence of structured capacity-building	• Offers concessional capital for DRE projects • Enhances FI capacity to assess and finance rural energy solutions

improve productivity and resilience.			on- and off-farm for integration	access among end-borrowers	programs on project structuring	

Figure 12. Summary of priority technologies within the scope of IGFF interventions

Appendix 1 – India's physical climate risk landscape

121. While India's clean energy transition is critical for decarbonizing its economy, the country's vulnerability to climate risks presents additional barriers to progress. Rising temperatures, shifting precipitation patterns, and increasing extreme weather events directly affect key sectors like energy, agriculture, and transportation, amplifying existing inequalities and developmental challenges.

Climate change trends

122. **India is the seventh-largest country in the world by geographical area, with a diverse geography.** The country is situated between 6°44'N to 35°30'N latitude and 68°7'E to 97°25'E longitude, with a total land area of 3,287,260 square km. It shares land borders spanning approximately 15,200 km and has a coastline of 7,516 km. It boasts a diverse geography that encompasses a wide range of ecosystems, including towering mountain ranges, expansive deserts, fertile plains, dense jungles, and a coastline exceeding 8,000 km, which supports a rich variety of marine ecosystems. This geographical diversity gives rise to equally varied climatic conditions, ranging from tropical to alpine, with extremes of heat and cold, aridity and humidity, and rainfall patterns that span from negligible to torrential.

123. **The country's climate is primarily influenced by its geographical diversity.** India's diverse landscapes include the Himalayan Mountain range in the north, stretching over 2,500 km, which serves as a climatic barrier and significantly influences the country's weather patterns. South of the Himalayas lie the Indo-Gangetic plains, rich in fertile alluvial soil and ideal for agriculture. In the west, the Thar Desert dominates with its arid conditions, while the central region comprises three main plateaus: the Malwa Plateau in the west, the Deccan Plateau covering much of southern India, and the Chota Nagpur Plateau in the east. India's coastal regions and offshore islands add further diversity. The Western Coastal Plain, bordered by the Western Ghats and the Arabian Sea, experiences the earliest rains of the monsoon season, which begins in June. The Eastern Coastal Plain, lying between the Eastern Ghats and the Bay of Bengal, is broader and features fertile deltas conducive to agriculture. The northeastern part of the country is characterized by hilly terrain and dense evergreen forests, which receive some of the highest rainfall during the monsoon season. Additionally, India's offshore islands, such as the Andaman and Nicobar Islands in the Bay of Bengal and the Lakshadweep Islands in the Arabian Sea, are notable for their extensive coral reefs and unique ecosystems. In effect, while the northern regions exhibit a continental climate with hot summers and cold winters, the coastal areas experience relatively stable, warmer temperatures year-round, accompanied by frequent rainfall.

124. **India's monsoons are a defining feature of its climate, with 75% of the country's annual rainfall received during the southwest monsoon albeit spatial variability**. The southwest monsoon season, spanning June to September, is the primary rainy season, delivering the majority of the country's annual precipitation. The retreat of the southwest monsoon is followed by the northeast monsoon, which occurs between October and December, bringing additional rainfall to certain regions, particularly in southern India. Rainfall during the southwest monsoon ranges from 150 to 270 mm per month on average, while the northeast monsoon typically brings between 10 and 75 mm per month. India's rainfall patterns are marked by significant year-to-year variability due to influences such as the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole. Figure 1 shows India's seasonal cycle of climatology between the years 1991–2020[187].

[187] While this figure provides a useful representation of the national average, it does not capture the geographical diversity or the variability of these trends across different regions; World Bank Group, *"Climate risk country profile: India"*, 2021.

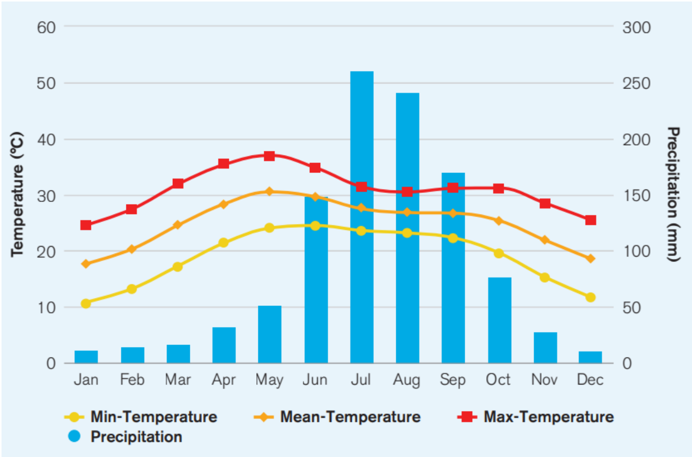

Figure 13. Average monthly mean, max, and min temperatures and rainfall in India (1991-2020)

Source: World Bank, 2021

125. **The country's monsoon rainfall patterns have remained largely stable over the past century, but recent decades reveal significant regional declines, particularly in northern and eastern states.** Historical precipitation trends in India are heavily influenced by the El Niño-Southern Oscillation (ENSO), which raises sea surface temperatures and reduces monsoon rainfall. While inter-annual variability is notable, the total rainfall during the Indian summer monsoon has remained relatively stable from 1901 to 2023, with a slight decreasing trend observed in recent decades, as indicated in Figure 14. Analysis of rainfall data from the India Meteorological Department (IMD) Observational Network reveals significant declines in southwest monsoon rainfall between 1989 and 2018 in five states: Bihar, Meghalaya, Nagaland, West Bengal, and Uttar Pradesh. Additionally, annual rainfall in these states has shown significant decreasing trends. Other states, however, have not exhibited notable changes in southwest monsoon rainfall during the same period.[188]

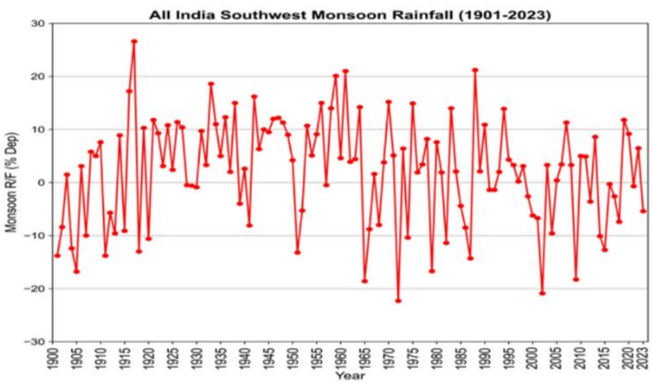

Figure 14. Percentage departure of area-weighted average monsoon season rainfall over India as a whole, 1901-2023

126. **Like its precipitation trends, temperature patterns also exhibit significant seasonal and regional variations.** During the coldest months of December and January, the mean maximum temperature varies from 33°C in some parts of the country to about 12°C in the plains of the north, while the mean minimum temperature varies from about 25°C in the extreme south to about 3°C in the plains of the north. Summers (May–September) are characterized by consistently high temperatures across much of the country, except in the mountainous regions, while winters (November–March) bring cooler temperatures and dry weather, particularly in the

[188] Ministry of Environment, Forest and Climate Change, "India: Fourth Biennial Update Report to the United Nations Framework Convention on Climate Change", 2024.

northern and central regions. Arid and semi-arid climates dominate western India, including the Thar Desert, which receives less than 300 mm of annual rainfall. In contrast, the southwestern region experiences a wet tropical climate with annual precipitation often exceeding 1,500 mm. The east coast and central India see high temperatures and precipitation, heavily influenced by the monsoon, which can vary greatly between years. Central India, in particular, experiences more pronounced seasonal temperature fluctuations, further contributing to the diversity of the country's climatic zones.

127. **India's average temperatures have been steadily increasing over the last century, with maximum temperatures rising faster than minimums, particularly in northern and northeastern regions.** Over the period 1901–2023, India's average annual mean temperature increased by 0.66°C per century, with maximum temperatures showing a sharper rise of +1.01°C per century compared to +0.31°C for minimum temperatures.

128. This warming trend is most pronounced during the post-monsoon season (+1.0°C per century), followed by the winter (+0.83°C per century) and monsoon (+0.74°C per century) seasons. Over the past three decades, temperature increases have been concentrated in the northern, central, and northeastern parts of the country, with daily maximum temperatures rising more prominently than minimums. Data from the Berkeley Earth Dataset indicates that while warming has occurred across all of India in the 21st century, India's warming rate has been below the global average, with the strongest increases observed in northern and northeastern regions.[189]

129. **Recent decades have been the warmest on record, with 2023 standing as the second warmest year since 1901.** The year 2023 recorded a mean surface air temperature of +0.65°C above the 1981–2010 average, making it the second warmest year since 1901, after 2016 (+0.71°C). Twelve of the 15 warmest years on record have occurred in the past 15 years (2009–2023). The most recent decades—2013–2022 and 2014–2023—were the warmest on record, with temperature anomalies of +0.41°C and +0.46°C, respectively.

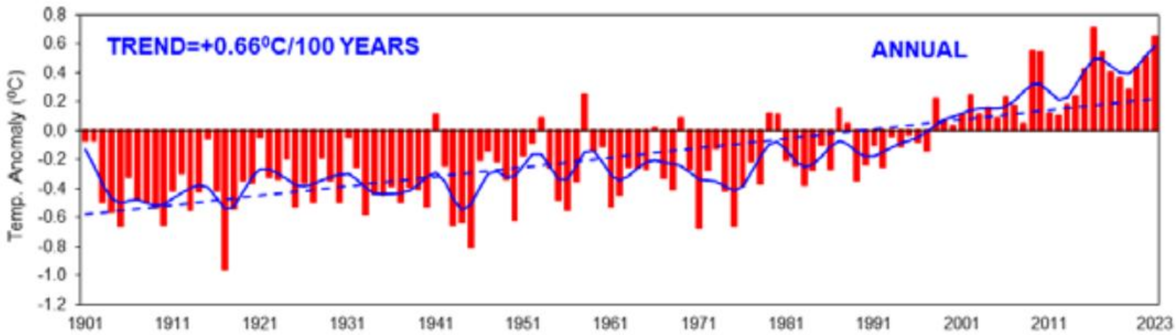

Figure 15. All India mean temperature anomalies, 1901-2023

130. **India is particularly vulnerable to the adverse effects of climate change, given its climate and socio-economic profile.** According to the Germanwatch Global Climate Risk Index 2021, India is the 7th-most affected country by weather-related losses and climate risks.[190] With a population of 1.5 billion, of which 30% live below the poverty line, these risks are amplified by the intersection of (the physical events themselves), exposure (the extent to which people, assets, and systems are in harm's way), and vulnerabilities (the susceptibility of those exposed to suffer harm) across regions, sectors, and groups of population.[191] **It is estimated that three out of**

[189] Carbon Brief, "Mapped: How every part of the world has warmed – and could continue to. Infographics", 2018.
[190] https://www.germanwatch.org/en/19777
[191] German Watch, Global Climate Risk Index, 2021

four people in India are likely to be affected by some form of climate change.[192] According to IPCC, crop yields for staples like rice, wheat, and maize are projected to decline by 10% to 30% by 2050 due to increased temperatures and altered rainfall patterns. Declining agricultural productivity, along with rising cereal prices could increase India's national poverty rate by 3.5%, pushing an additional 50 million people into poverty by 2040.[193] Health-related issues, such as stunting, are expected to rise by 35%, disproportionately affecting the poor.[194] In 2021, heat exposure led to a loss of 167 billion potential labor hours in India, translating to an income loss of approximately USD 159 billion, or 5.4% of the country's GDP.[195] Hence, these risks have profound implications for the country's priorities concerning overall development and poverty alleviation.

131. **Climate risks can be broadly categorized into physical risks and transitional risks.** Physical risks include (i) acute risks, such as extreme weather events like cyclones, floods, and heatwaves, which can cause immediate and widespread damage to infrastructure, disrupt livelihoods, and lead to loss of life, as well as, (ii) chronic risks, such as rising temperatures, sea-level rise, and long-term shifts in precipitation patterns, which erode economic productivity, deplete natural resources, and exacerbate food and water security challenges. Transitional risks emerge as economies adjust to a low-carbon future, encompassing changes in policies, technologies, and market dynamics. These risks can disproportionately affect sectors dependent on fossil fuels, as well as vulnerable communities reliant on traditional livelihoods.

Overview of Key Climate Impacts for India

132. **India's climate risks are driven by four key phenomena - rising temperatures, shifting precipitation patterns, climatic and hydrological variability, and extreme weather events.** These factors collectively *shape India's* vulnerabilities across populations and sectors, leading to widespread social and economic impacts. They result in disruptions to livelihoods, infrastructure, and essential services, causing significant losses that hinder development and resilience efforts. Detailed projections across these four areas are provided below, with the summary of impacts furbished as Table 8 at the end of this section.

Changes in temperature

133. **By the 2050s, average temperatures are expected to rise by approximately 2.4°C to 4.4°C, depending on the region and emissions scenario.** Average temperatures in India vary widely depending on the region. In the Thar Desert, temperatures can exceed 45°C during the day in summer, while in the winter, northern India frequently experiences temperatures below 5°C.[196] The Himalayan north experiences sub-zero temperatures during the winter months. Given the climatic variability, projected temperature changes show regional variabilities in terms of warming by 2050 relative to 1985-2005 baseline, as shown in Table 8 below.

Table 8. Projected Temperature Changes in India[197]

Projected Temperature Changes (2050s relative to 1986-2005)		
Region	*Delta*	*Range*
North India	+1.8°C	+1.2 to +2.6°C
South India	+1.6°C	+1.0 to +2.3°C

[192] CEEW, Preparing India for Extreme Climate Events, 2020.
[193] https://cdn.odi.org/media/documents/ODI-JR-CostClimateChangeIndia-final.pdf
[194] World Bank, India: Climate Change Impacts, 2013.
[195] https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-India-Web.pdf
[196] https://rmcnewdelhi.imd.gov.in/MET_CENTRES/MCJPR/jpr_upload/uploads/THAR%20%20FINAL.pdf
[197] India - Trends & Variability - Historical | Climate Change Knowledge Portal (worldbank.org)

134. Depending on the Representative Concentration Pathways (RCPs) considered, projections for temperature increases vary:

- RCP 2.6: Represents a scenario where significant efforts are made to reduce greenhouse gas emissions, leading to a moderate increase in temperatures.
- RCP 4.5: A stabilization scenario where emissions peak around 2040 and then decline.
- RCP 6.0: Assumes a slower reduction in emissions, with a significant increase in temperatures.
- RCP 8.5: The business-as-usual scenario with no significant efforts to reduce emissions, resulting in the highest temperature increases.

135. Given the current global emission trends and the efforts required to limit temperature rise, the RCP 4.5 and RCP 6.0 scenarios are considered more relevant for planning climate mitigation and adaptation actions. According to these scenarios, a temperature rise in the range of 2.4°C to 4.4 °C is projected for India, under RCP 4.5 and RCP 8.5 pathways respectively, with average monthly temperatures potentially reaching up to 35-40°C during peak summer months (Figure 16).

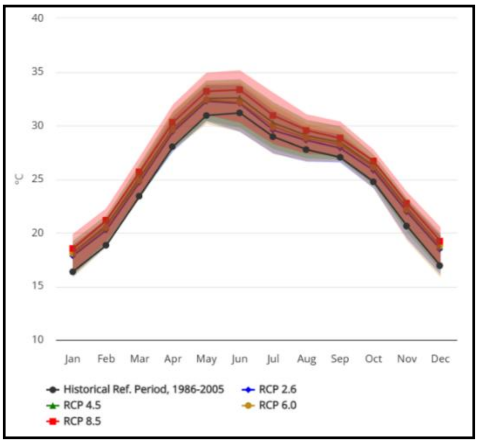

Figure 16. Projected monthly mean temperature in India over 2040 – 2059, under RCP 2.6; RCP 4.5; RCP6.0; RCP 8.5[198]

Changes in precipitation

136. **Rising temperatures are intensifying rainfall events while reducing the overall number of rainy days, leading to more concentrated and erratic precipitation patterns.** India's monsoon season delivers over 80% of the country's annual precipitation, critically sustaining agriculture in regions like the Indo-Gangetic Plain. The average annual rainfall varies dramatically, from as high as 1,500 mm in the southwestern region to as low as 300 mm in the arid west.[199] In recent years, there has been a shift in the recent period toward more frequent dry spells (27% higher during 1981–2011 relative to 1951– 1980) and more intense wet spells during the summer monsoon season. The frequency of daily precipitation extremes with rainfall intensities exceeding 150 mm per day increased by about 75% during 1950–2015.

137. During the 21st century, climate models project an increase in summer monsoon mean rainfall (6-8% under RCP 4.5 and RCP 8.5 respectively) as well as an increased frequency of heavy rain occurrences over most parts of India. The interannual variability of summer monsoon rainfall is projected to increase too. Such change patterns are expected to trigger much more severe and longer droughts as well as greater flooding in large parts of India that can disrupt livelihoods, and infrastructure and adversely impact water availability in India. Whereas

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[198] Ibid.
[199] https://climateknowledgeportal.worldbank.org/sites/default/files/country-profiles/15503-WB_India%20Country%20Profile-WEB.pdf

the total annual rainfall is projected to increase, particularly along the west coast and northeastern India in the 2050s relative to 1986-2005 (Table 9). However, since variability in monsoon rainfall is also expected to rise, this will result in longer dry spells interspersed with heavy rain episodes.

Table 9. Projected Rainfall Changes in India[200]

Projected Rainfall Changes (2050s relative to 1986-2005)	
Region	*Delta Range*
Western Ghats	+5% to +15%
Northeast India	+10% to +20%

Climatic and hydrological variabilities

138. Historical trends in precipitation are strongly influenced by El Niño Southern Oscillation (ENSO), a climate pattern which increases sea surface temperatures in the central and eastern tropical Pacific Ocean, and reduces summer monsoon rainfall in India, as shown in Figure 17. The reduction in summer monsoon rainfall leads to drought conditions, adversely affecting crop yields and water availability for irrigation. For instance, El Niño years have been associated with decreased yields in major crops like rice and wheat.[201,202] These conditions can lead to food shortages and increased prices for staple foods, affecting food security. Farmers, particularly those dependent on rain-fed agriculture, face significant income losses. Livestock farming is also impacted as water scarcity affects fodder availability, leading to reduced milk production and overall livestock health. The broader economic impact includes increased expenditure on food imports to mitigate shortages and potential inflation due to higher food prices.[203]

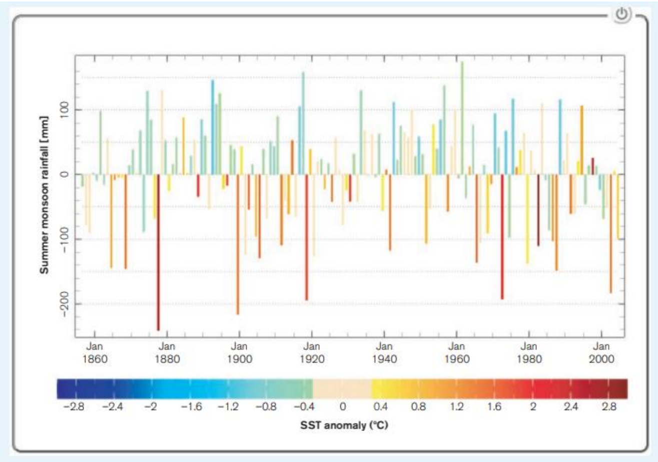

Figure 17. The Historical Relationship between summer monsoon rainfall in India and El Niño Southern Oscillation (ENSO) indicated by Sea-Surface Temperature (SST) anomalies (higher SST is associated with ENSO)[204]

139. **Additionally, the Indian Ocean Dipole (IOD) also has significant impacts on the monsoonal patterns.**[205] Positive IOD events, which enhance monsoon rainfall, can benefit agriculture by ensuring adequate water supply for crops, thereby boosting food production. This can also increase hydroelectric power generation, an

[200] Ibid.
[201] Impacts of El Niño Southern Oscillation on the global yields of major crops | Nature Communications
[202] Impact of El-Nino and La-Nina on Indian Climate and Crop Production | SpringerLink
[203] The 2023-24 El Niño event and its possible global consequences on food security with emphasis on India | Food Security (springer.com)
[204] IRI Data Library, International Research Institute for Climate and Society, 2018; Accessed 02/12/2019
[205] The IOD involves periodic oscillations in sea surface temperatures between the western and eastern Indian Ocean. During a positive IOD phase, warmer sea surface temperatures in the western Indian Ocean and cooler temperatures in the eastern part can enhance the southwest monsoon, leading to above-average rainfall in India. Conversely, a negative IOD, characterized by cooler sea surface temperatures in the western Indian Ocean and warmer temperatures in the eastern part, can suppress the monsoon, resulting in reduced rainfall and potentially exacerbating drought conditions in India.

important component of India's renewable energy mix. On the other hand, negative IOD events can lead to dry spells and drought, adversely affecting crop yields and water availability. This poses challenges for food security and can increase reliance on irrigation, thereby raising energy demand for pumping water. Moreover, reduced rainfall during negative IOD phases can impact hydroelectric power generation, leading to greater dependence on fossil fuels and affecting energy security.

140. **The reduction in glacier volume and inconsistent monsoon patterns are likely to lead to severe water scarcity for large swathes of the population, especially in the Indo-Gangetic Plains.** The Himalayan glaciers have experienced a marked retreat, which research from the Indian Institute of Science indicates could shrink by up to 85% under high emission scenarios by 2100. The accelerated melting of glaciers due to rising temperatures is leading to increased water runoff initially, followed by reduced water availability in the long term. This situation is compounded by the unpredictability of monsoon rains, which are the primary source of water replenishment for many regions. Climate change-induced shifts in monsoon patterns, such as delayed onset, erratic rainfall, and more intense precipitation events, further exacerbate water scarcity issues by disrupting traditional water management practices and infrastructure. This glacier retreat threatens the flow of the Indus, Ganges, and Brahmaputra rivers, posing a threat to over 500 million people, who rely on these water sources for agriculture, drinking, and energy generation.[206]

Extreme weather events

141. **India faces some of the highest disaster risk levels in the world, ranked 32nd out of 191 countries by the 2019 INFORM Risk Index.** The Inform Risk Index identifies specific risks across a country to support decisions on prevention, preparedness, response and a country's overall risk management. India has very high exposure to flooding (ranked jointly 13th), including, riverine, flash, and coastal, as well as high exposure to tropical cyclones and their associated hazards (ranked jointly 14th) and drought (ranked jointly 24th). Disaster risk in India is also driven by its social vulnerability. India's vulnerability ranking (44th) is driven by its high levels of socioeconomic deprivation. India scores markedly better in terms of its coping capacity. Given that 65% of India's landscape is drought-prone, 12% is flood-prone, and 8% is susceptible to cyclones, the future projections of regional as well as global climate models indicate a high likelihood of an increase in frequency, intensity and impact area of extreme weather events under both RCP 4.5 and RCP 8.5 scenarios.[207]

142. The section which follows analyses climate change influences on the exposure component of risk in India.

Table 10. Selected indicators from the INFORM 2019 Index for Risk Management for India. For the Sub-Categories of Risk (e.g. "Flood"). Higher scores represent greater risks. Conversely, the most at-risk country is Ranked 1st. Global averages are shown in brackets[208]

Flood (0-10)	8.4 [4.5]
Tropical Cyclone (0-10)	7.2 [1.7]
Drought (0-10)	6.2 [3.2]
Vulnerability (0-10)	4.9 [3.6]
Lack of Coping Capacity (0-10)	4.3 [4.5]
Overall Inform Risk Level (0-10)	5.4 [3.8]
Rank (1-191)	32

[206] World Bank, Country Profile: India (2021)
[207] Refer to Chapter 6 and 7 on frequency of droughts and floods, as well as storms under current and projected scenario on a following link: Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India | SpringerLink.
[208] Inform Risk Country Profile: India

143. The following table depicts the projected hazard scores for India with a mean and maximum (max) score. The scores range from 1 (low) to 10 (Very high). The mean value for India is calculated by adding up all hazard values of the separate 50 km x 50 km grids in the country and dividing them by the total amount of grids. The max score is the highest hazard value in India. A comparison of mean and max scores shows that there is variability within India regarding almost all hazards, mainly river floods, earthquakes and coastal floods.

Table 11. The projected climate hazard risk scores out of 10 for 2050 under SSP 2-4.5, based on the INFORM risk index, with higher scores indicating greater risk (Source: INFORM Risk Index, 2022)[209]

Overall Climate Change Risk		Hazard & Exposure	Vulnerability	Lack of Coping Capacity	
5.3		**7.4**	**4.7**	**4.2**	
Earthquake	**Tsunami**	**River Flood**	**Coastal Flood**	**Cyclones**	**Droughts**
8.3	7.8	9.2	7.7	7.7	4.4

KEY	0-2	2-4	4-6	6-8	8

Heatwaves

144. **India is increasingly experiencing severe and frequent heatwaves, particularly affecting the northern and central regions.** In March 2022, India faced its hottest month since records began 122 years ago, a record that was subsequently broken in both 2023 and 2024. By May 2024, Delhi recorded temperatures exceeding 50°C, resulting in a critical water shortage and exacerbating the city's vulnerability to climate impacts.[210] City authorities have warned that heatwaves could also lead to power grid failures, further exacerbating the crisis.

145. **These extreme temperature events pose significant health risks, especially to the elderly, children, and outdoor workers.** The rising temperatures exacerbate pre-existing conditions such as cardiovascular and respiratory diseases, leading to heat stroke, adverse pregnancy outcomes, disrupted sleep patterns, mental health issues, and increased injury-related deaths. Between 2000-2004 and 2017-2021, there was a 55% rise in deaths attributed to extreme heat.[211] Since March 2024, there have been over 16,000 heat stroke cases and 60 heat-related deaths reported, although the actual numbers are likely much higher.[212] The socio-economic implications of these heat waves are profound. In 2021, exposure to extreme heat resulted in the loss of 167.2 billion potential labour hours in India, equating to about 5.4% of the country's GDP.[213] This loss disproportionately affects outdoor workers, such as those in agriculture and construction, who are most vulnerable to heat stress.[214]

146. **Heatwaves that, in the past, occurred once every 10 years with minimal human influence are projected to become significantly more frequent with increasing global temperatures.** With 1.5°C of warming, these heatwaves are expected to occur 4.1 times more frequently. If global temperatures rise by 2°C, the frequency will increase to 5.6 times, and with a 4°C rise, they could occur 9.4 times more often. Not only are heat waves increasing in frequency due to climate change, but they are also lasting longer and becoming hotter,

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[209] Inform Risk Country Profile: India
[210] Water crisis amidst heatwave: Delhi government calls emergency meeting | Delhi News - Times of India (indiatimes.com)
[211] The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels - The Lancet
[212] India faces record-breaking heatwave worsened by climate change - India Today
[213] The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels - The Lancet
[214] More frequent heatwaves in India are putting lives at risk | World Economic Forum (weforum.org)

too. At 1.5°C of warming, the intensity of heatwaves will rise by 1.9°C, at 2°C of warming by 2.6°C, and at 4°C of warming by 5.1°C.[215] During March–April 2022, India and Pakistan experienced a heatwave that was 30 times more likely to have happened because of climate change.[216]

Droughts

147. **India has been experiencing increasingly severe and frequent droughts, with projections indicating an increase of two or three drought periods per decade for India.** Parts of India, especially the Deccan Plateau, northwest, and south, frequently experience drought conditions due to erratic monsoon rains. India's drought-prone area has expanded by 57% since 1997.[217] Between 2020 and 2022, nearly two-thirds of the country faced drought conditions. Over the past decade, one-third of India's districts experienced more than four droughts, affecting about 50 million people annually.[218] The change in drought frequency is projected to increase by more than two to three severe droughts per decade over the majority of India.[219]

148. **Droughts in India are often linked to the ENSO, which disrupts the monsoon patterns, causing prolonged dry spells that affect crop yields and farmer incomes.** The 2016-2018 drought, one of the most severe in the last 150 years, resulted from a 40% deficit in northeast monsoonal rainfall through the three years, affecting lives and livelihoods throughout Southern India, where over 60% of the rural population is engaged in agriculture and allied activities.[220] Precipitation during the 2022 monsoon has been notably poor in Uttar Pradesh and Jharkhand, resulting in rising farmer stress in these regions. As of mid-August 2022, Uttar Pradesh had received 44% less rain than normal. Bihar, Jharkhand, and West Bengal also faced grim situations, with an average of around 30 per cent less rainfall than usual.[221] This resulted in entire rice crops being lost in some cases, and sowing cycles delayed in other cases.

149. **This had a cascading effect on food prices and rural incomes, pushing many farmers into debt and exacerbating rural poverty.** Livestock also suffer due to the scarcity of water and fodder, leading to reduced milk production and higher mortality rates. Droughts also strain the water supply for drinking and sanitation, leading to health crises in affected regions.[222] To add to this, more than 60% of India's agriculture is rain-fed, making the country highly dependent on groundwater. During droughts, it is not uncommon for farmers to turn to groundwater extraction, often powered by diesel pumps. This increases their operational costs, results in over-exploitation of groundwater resources, and contributes to higher greenhouse gas emissions coming from the agriculture sector.

Floods

150. **India is among the most flood-prone countries globally, largely due to its extensive river systems and monsoonal climate** and ranks 13th on the INFORM Risk Index.[223] Major rivers like the Ganges, Brahmaputra, and Godavari experience seasonal flooding exacerbated by heavy monsoon rains, affecting millions annually. Urban flooding, caused by intense and unplanned urbanization, has also become increasingly common in cities like Mumbai and Chennai. Historically, floods affect over 4.8 million people each year on average, and adversely impact the GDP of India by USD 14 billion, causing extensive damage to property and loss of life.[224]

151. **The impacts of flooding are severe, with significant disruptions to lives and livelihoods. Floods destroy homes, displace communities, and lead to loss of life.** Agriculture suffers tremendously, with crops being submerged and destroyed, leading to food shortages and loss of income for farmers. Floods also damage

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[215] Synthesis Report — IPCC
[216] The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels
[217] https://www.unccd.int/resources/publications/drought-numbers
[218] https://www.indiatoday.in/diu/story/droughts-india-world-climate-change-global-warming-monsoons-un-1989548-2022-08-18
[219] https://research.iitj.ac.in/publication/impact-of-climate-change-on-drought-frequency-over-india
[220] https://india.mongabay.com/2021/05/southern-indias-2016-2018-drought-was-the-worst-in-150-years/
[221] https://www.indiatoday.in/diu/story/droughts-india-world-climate-change-global-warming-monsoons-un-1989548-2022-08-18
[222] https://www.sciencedirect.com/science/article/abs/pii/S2212420919310180
[223] https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk
[224] https://climateknowledgeportal.worldbank.org/sites/default/files/country-profiles/15503-WB_India%20Country%20Profile-WEB.pdf

critical infrastructure such as roads, bridges, and power lines, disrupting transportation and communication networks. The health sector is not spared, as floods lead to the spread of waterborne diseases, exacerbate existing health issues, and overwhelm healthcare facilities, some of which might be situated in flood-prone regions.[225]

152. **Climate change projections indicate an increase in the frequency and intensity of flooding events.** Rising temperatures are expected to enhance the monsoon's variability, leading to more intense and erratic rainfall patterns. In India, instances of heavy rainfall have risen by almost 85% since 2012.[226] IPCC reports that extreme precipitation events are likely to become more common, increasing the risk of flooding. Sea level rise also poses a significant threat to coastal areas, increasing the risk of storm surges and coastal flooding.

Cyclones

153. **The long coastline of over 7,500 kilometres along the Bay of Bengal and the Arabian Sea exposes India to tropical cyclones.** The eastern coast is particularly susceptible, witnessing about five to six cyclones each year. They are often accompanied by strong winds, heavy rainfall, and storm surges, leading to significant coastal and inland flooding. For instance, Cyclone Amphan in 2020 resulted in widespread destruction in West Bengal and Odisha. The cyclone was the most powerful to hit the River Ganges Delta since the 1999 Odisha Super Cyclone, causing the largest displacement that year with 2.4 million people displaced in India.[227] In West Bengal, at least 86 people lost their lives, primarily due to electrocution or the collapse of homes. The state government estimated the damage at 1.02 trillion Indian Rupees (USD 13.5 billion), directly affecting 70 per cent of the state's population. In Odisha, the power grid sustained damage estimated at 3.2 billion Indian Rupees (USD 42 million). The cyclone claimed four lives in Odisha—two from collapsing structures, one by drowning, and one from head trauma. Overall, 4.4 million people across ten districts in Odisha were affected by the cyclone in various ways.[228]

Table 12. Summary of climate change impacts on India

Increased temperature	Shifts in precipitation patterns	Increased hydrological variability	Extreme Weather events
Increase from 2.4°C to 4.4 °C under Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 respectively.[229]	Increase in the summer monsoon mean rainfall from 6% to 8% under RCP 4.5 and RCP 8.5. Increased frequency of heavy rain occurrences and variability.[230] At 4.4 °C an extremely wet monsoon that currently has a chance of occurring only once in 100 years is projected to occur every 10 years by the end of the century.	The effect of increased temperatures will result in further thermal expansion of seawater and the melting of glaciers (especially in the Himalayas). This, along with changing monsoon patterns will alter river flows and groundwater recharge rates.	Storms, heat waves, droughts, cyclones and floods are predicted to increase both in frequency as well as intensity under future climate change scenarios, resulting in considerable losses and damages to infrastructure, as well as loss of life.

[225] https://onlinelibrary.wiley.com/doi/abs/10.1002/wmh3.429
[226] https://www.worldbank.org/en/news/feature/2023/08/17/india-managing-the-complex-problem-of-floods-and-droughts
[227] Cyclone Amphan was largest source of displacement in 2020, says latest IPPC report | Latest News India - Hindustan Times
[228] India: Cyclone Amphan Final Report (DREF n° MDRIN025) - India | ReliefWeb
[229] https://climateknowledgeportal.worldbank.org/sites/default/files/country-profiles/15503-WB_India%20Country%20Profile-WEB.pdf
[230] Ibid.

Sector-wise Climate Impact Pathways for IGFF Priority Areas

154. **Climate risks significantly challenge key sectors critical to India's clean energy transition, undermining efforts to advance the transition, ensure economic stability, and build resilience.** Rising temperatures, extreme weather events, and shifting hydrological patterns disrupt agricultural productivity, damage infrastructure, strain energy systems, and destabilize industrial output. These cascading impacts not only threaten livelihoods and food security but also increase costs and hinder progress toward sustainable development.

155. **The sectoral analysis provided below reveals how climate risks manifest across energy, industry, transportation, and industry**, highlighting the pathways through which they amplify vulnerabilities and create barriers to resilience and growth. Understanding these impacts is critical for designing targeted interventions that can address some of the key climate challenges while supporting India's clean energy and development goals.

Energy

156. **Climate change poses significant challenges to India's energy sector, both directly and indirectly.** One of the primary impacts is on water availability, critical for hydroelectric plants and cooling thermal power stations. Changing precipitation patterns and rising temperatures affect river flows, potentially reducing the efficiency of hydropower generation. Glacial melts in the Himalayan rivers, upon which a substantial portion of India's hydropower relies, could lead to variability in power generation, particularly during drought years. This variability underscores the vulnerability of India's energy infrastructure to climate-induced water scarcity.

157. **Thermal power plants, which constitute a significant portion of India's energy mix, face challenges due to reduced water availability for cooling purposes.** Rising temperatures can hinder the efficiency of cooling processes, leading to decreased power outputs. Heatwaves can force plants to curtail electricity production to prevent equipment damage, while lower water levels in reservoirs may necessitate temporary shutdowns.[231] Between the years 2013 and 2016, water shortages cost India's thermal power plants 30 TWh in potential electricity generation, equivalent to ~2% of India's annual consumption.[232] These challenges highlight the need for innovative solutions to adapt thermal power plants to changing climate conditions.

158. **Renewable energy sources, such as solar and wind, are also impacted by climate change**. Variability in solar irradiance levels and changing wind patterns affect the reliability of these resources. While renewable energy is crucial for reducing greenhouse gas emissions, its variability poses challenges for grid management and reliability. Addressing these challenges requires a comprehensive approach, integrating climate resilience into energy planning and infrastructure development.

159. **Moreover, the vulnerability of energy infrastructure to extreme weather events is a growing concern.** Cyclones, floods, and storms, exacerbated by climate change, pose risks to power lines, substations, and production facilities. For instance, the 2018 floods in Kerala caused significant damage to energy infrastructure, resulting in widespread power outages and long-term impacts on energy supply reliability. In May 2024, Jaisalmer experienced extreme heat with daytime temperatures reaching 50°C. This unprecedented heatwave caused significant disruptions, including a windmill catching fire due to the intense heat.[233] Hence, enhancing the resilience of energy infrastructure is paramount to ensuring an uninterrupted energy supply in the face of increasingly frequent and severe weather events.

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[231] https://research.wur.nl/en/publications/power-generation-system-vulnerability-and-adaptation-to-changes-i
[232] https://www.wri.org/insights/droughts-and-blackouts-how-water-shortages-cost-india-enough-energy-power-sri-lanka#:~:text=Our%20analysis%20found%20that%2C%20in,percent%20of%20India's%20annual%20consumption.
[233] Windmill catches fire in Jaisalmer due to extreme heatwave | Jaipur News - Times of India (indiatimes.com)

160. **Finally, as temperatures rise, the demand for cooling, particularly air conditioning, is expected to surge, resulting in increased demand for energy consumption.** This increased demand strains the power grid, leading to higher peak loads and necessitating additional capacity. For example, in May 2024, a record daytime temperature in Delhi pushed power demand to a new high of 8,302 MW, surpassing the previous record of 8,000 MW set earlier in the month. This marked the twelfth consecutive day with peak demand over 7,000 MW, compared to just one instance in May 2023.[234] Addressing this rising demand requires investments in energy-efficient cooling technologies and grid optimization measures.[235] Overall, addressing the impacts of climate change on India's energy sector requires proactive adaptation strategies and investments in resilient infrastructure to ensure a reliable, sustainable, and climate-resilient energy system for the future.

161. **The cascading effects of climate risks on energy infrastructure also ripple through other sectors, such as transportation, agriculture, and industry, compounding vulnerabilities and increasing adaptation costs.** Addressing these interconnected challenges is essential to ensure that India's clean energy transition remains resilient and inclusive.

Industry

162. **India's industrial sector is increasingly exposed to climate risks, particularly extreme weather events and shifts in resource availability.** Industries that rely heavily on water- and energy-intensive inputs, such as steel, textiles, and chemicals, face challenges due to seasonal water scarcity, erratic energy supply, and rising operational costs. In 2019, a severe drought in the southern state of Karnataka significantly impacted steel production. JSW Steel, one of India's largest steelmakers, reported a reduction in production capacity by up to 40% due to water shortages.[236] Climate change impacts on the growth and production of natural fibers have led to a shortage of raw materials in the textile industry, affecting production numbers in recent years.[237] In addition, thermal power shortages and disruptions in energy grids caused by extreme weather events can lead to production delays and financial losses, further straining industrial output.

163. **Micro, Small, and Medium Enterprises (MSMEs), which account for 30% of India's GDP and employ over 110 million people, are particularly vulnerable.[238]** These businesses often operate with limited resources and are concentrated in climate-sensitive sectors such as manufacturing, food processing, and textiles. Heatwaves, droughts, and flooding can disrupt supply chains, damage assets, and increase input costs, threatening the survival of small enterprises. In December 2023, cyclone *Michaung* hit Tamil Nadu, impacting 4,800 MSME units across 24 industrial estates, leading to losses worth at least USD 360 million. In 2022, Gujarat industry was affected by heavy rainfall resulting in disruption of goods' movement and factory production leading to about 600 million USD in losses.[239] Additionally, the lack of access to affordable financing for climate adaptation further hampers their ability to build resilience against these impacts.

164. **Adapting to these challenges requires a focus on enhancing energy efficiency, promoting green technologies, and building climate-resilient industrial systems.** For MSMEs, targeted interventions such as access to climate finance, technical support for adaptation, and incentives for clean energy adoption can significantly improve their capacity to weather climate impacts while fostering sustainable growth.

[234] Delhi Weather and AQI Today: Warm start at 28.95 °C, check weather forecast for July 10, 2024 | Latest News Delhi - Hindustan Times
[235] USAID, Energy-Efficient Technologies
[236] Afonso and Chaudhary, "In an increasingly water-scarce India, life's changing for steelmakers, and how", in Economic Times, 2019.
[237] CEEW, "How Clean Energy Could Shape India's Textile Industry: Challenges and Opportunities", 2022.
[238] Ministry of Micro, Small, and Medium Enterprises, "Contribution of MSME Sector in GDP", 2024.
[239] WRI India, "Indian MSMEs Need to Embrace Climate Adaptation for Survival", 2024.

Transportation

165. **India's transportation sector faces diverse and interconnected challenges from climate change, impacting infrastructure durability, operational efficiency, and economic productivity.** Rising temperatures and intense heatwaves accelerate the degradation of infrastructure, including roads, railways, and bridges, leading to increased maintenance costs and shortened lifespans of critical assets. Additionally, extreme weather events such as floods and cyclones cause extensive damage, particularly in urban and coastal areas, where transportation networks are more susceptible to waterlogging, erosion, and structural failures.

166. **Operational disruptions are a growing concern as erratic precipitation patterns and flooding hinder public and freight transportation.** In 2018, Kerala experienced severe flooding that damaged over 10,000 km of roads and 280 bridges, with repair costs exceeding USD 3 billion. Such events additionally result in delays, restricted mobility, and higher costs, particularly affecting vulnerable populations who rely heavily on public transportation. Moreover, heatwaves drive up energy consumption for cooling mechanisms in vehicles, escalating operational costs for transport systems and increasing fuel dependency.

167. **The economic and social impacts of these disruptions are far-reaching, with disruptions to goods and services across sectors.** Transport interruptions obstruct the delivery of essential goods and services for businesses and people, raising costs across supply chains and limiting access to mobility for low-income populations at the time of an extreme event. Increased fuel consumption on hotter days not only raises costs for operators and users but also deepens the reliance on fossil fuels, counteracting efforts to transition to a low-carbon economy.

168. **Addressing** these challenges requires an integrated approach that prioritizes climate-resilient infrastructure, such as elevated roads, robust drainage systems, and durable construction materials, to withstand extreme weather impacts. Transitioning to low-carbon mobility solutions, including vehicle electrification, public transportation expansion, and the adoption of clean fuels, is equally critical. Such measures will not only reduce the sector's vulnerability to climate change but also align with India's broader goals of decarbonization, energy security, and sustainable development.

Agriculture

169. **The agricultural sector is most vulnerable to climate change and, conversely, the most important sector for adaptation in India.** The risks faced by the agricultural sector (and allied activities) include risks from extreme events, climate variability, low levels of productivity, as well as general conditions of socioeconomic well-being in rural regions of India. Seasonal water scarcity, rising temperatures, and increased drought risks threaten the country's food security. This vulnerability is particularly acute in rainfed agricultural areas, where 55% of cultivated land and 40% of plant production are subject to the vagaries of the monsoon.[240] Droughts and unseasonal rains, more frequent due to climate change, directly impact crop yields and rural livelihoods. Moreover, increased CO_2 levels might boost crop growth but can lower the nutritional quality of staple cereals, affecting dietary nutrition across populous regions. A 2020 study published by the Indian Agricultural Research Institute predicts significant yield declines for major crops like wheat and rice due to rising temperatures and changing rainfall patterns. Wheat yields could decrease by 6-25% by 2050 under various climate scenarios, which would critically impact food security given that wheat is a staple for over 200 million Indians.[241]

170. **These risks are disrupting the viability and productivity of various crops and livestock, thereby affecting farmer incomes, while also reshaping food consumption patterns in the country.** In March and April

[240] IFAD Country Strategic Opportunities Programme
[241] Indian Agricultural Research Institute, Climate Change and Indian Agriculture: Impact, Adaptation and Vulnerability

2022, northwest and central India experienced their hottest April in 122 years, with maximum temperatures reaching 37.8°C. This heatwave caused significant crop losses, including reductions in yields of wheat (10-34%), maize (18%), chickpea (19%), and various horticultural crops like mango, guava, tomato (40-50%), and cucumber (30-50%). Livestock and poultry production also suffered, with milk yields dropping by 11-15%, egg production by 4-10%, and mortality increasing up to 8% in broiler chickens. Fisheries in plains were impacted by water scarcity, highlighting the widespread effects of extreme heat across sectors. A study by the Indian Council for Research on International Economic Relations (ICRIER) found that climate change could reduce farm incomes by 15-25% in unirrigated areas and by 5-10% in irrigated areas.

171. **Compounding these challenges is the prevalence of small farm holdings, whose size and climate vulnerability are on the rise.** India's agricultural sector continues to serve as a crucial source of employment for nearly half of India's workforce. Of this 86% are classified as small and marginal farmers as per India's Agriculture Census 2015-16, meaning they own less than 2 hectares of land. Over the years, the average farm size has dwindled significantly because of diminished agricultural incomes, compounded by market linkage challenges for remote and small-scale farmers. This is resulting in an increasing share of small and marginal landholder farmers in the country thereby widening the bottom of the agricultural pyramid. Additionally, environmental issues such as groundwater depletion, soil erosion, and imbalanced fertilizer usage further exacerbate the sector's vulnerabilities.[242] Addressing these multifaceted challenges necessitates a concerted shift towards sustainable intensification of rainfed agricultural production, coupled with enhanced soil and water resource management practices.

172. A summary of climate impacts across IGFF priority sectors, highlighting vulnerabilities to temperature changes, precipitation shifts, and extreme weather events, is provided below in Table 13.

Table 13. Summary of climate impacts on IGFF priority sectors

Sector	Temperature changes	Precipitation changes	Extreme weather events
Energy	Higher temperatures increase energy demand for cooling, straining grids	Hydrological variability affects water availability for hydropower and thermal plants	• Floods and cyclones: Damage energy infrastructure, causing outages • Droughts: Reduce hydropower capacity and water for thermal cooling systems
Transportation	Heatwaves accelerate degradation of roads, railways, and bridges, increasing maintenance costs	Waterlogging from erratic precipitation damages transport infrastructure and disrupts mobility	• Floods: Cause transport delays and damage to infrastructure • Heatwaves: Increase energy demand for cooling in vehicles, raising costs and emissions
Industry	Heatwaves disrupt manufacturing processes	Reduced water availability limits production in water-intensive industries	• Floods: Damage industrial facilities and supply chains

[242] IFAD Country Strategic Opportunities Programme

	and reduce worker productivity		• Heatwaves: Increase energy costs for cooling industrial operations • Cyclones: Interrupt supply chains in coastal regions
Agriculture	• Heat stress reduces crop yields, particularly wheat and rice • Lower nutritional quality of staple crops due to elevated CO2 levels.	• Unpredictable monsoon patterns disrupt planting cycles and crop growth • Increased drought risks threaten rainfed agriculture	• Droughts: Impact water availability for irrigation, affecting productivity • Unseasonal rains and floods: Damage crops and infrastructure • Cyclones: Destroy farmland in coastal areas

Appendix 2 - India’s Climate Goals, Commitments, and Progress

173. **Climate Change is a global problem that requires collective actions and sharing of the global carbon budget or carbon space (for a particular temperature target) in a fair and equitable manner.** Despite India’s relatively low historical contribution to cumulative global GHG emissions and India’s minimal per capita GHG emission, India is committed to addressing the global action problem of climate change based on equity and the principle of common but differentiated responsibilities and respective capabilities (CBDR-RC), as enshrined in the United Nations Framework Convention on Climate Change (UNFCCC).

174. **India has been an active and leading voice in emphasizing the need for the world to take action to meet the intertwined challenges of sustainable development and poverty eradication as well as climate action.** This role includes its active participation in the formation and signature/ratification of the UNFCCC itself, its adherence to the letter and spirit of the Kyoto Protocol and active participation in its implementation. Despite its minimal responsibility for global warming, India has pro-actively worked towards global solutions including joining the Copenhagen Declaration, and the Cancun Agreements and eventually working actively for the finalization of the Paris Agreement.

India’s Climate Commitments

NDC Submissions to the UNFCCC

175. **In line with the above principles, India submitted an updated Nationally Determined Contribution in August 2022, in keeping with the provisions of the Paris Agreement to the 26th Conference of Parties to the UNFCCC.**[243] India’s updated Nationally Determined Contributions (NDCs) are currently as follows:

1. To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation, including through a mass movement for ‘LIFE’– ‘Lifestyle for Environment’ as a key to combating climate change
2. To adopt a climate friendly and a cleaner path than the one followed hitherto by others at corresponding level of economic development
3. To reduce the Emissions Intensity of its GDP by 45 percent by 2030, from the 2005 level
4. To achieve about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030, with the help of the transfer of technology and low-cost international finance, including from Green Climate Fund (GCF)
5. To create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030
6. To better adapt to climate change by enhancing investments in development programmes in sectors vulnerable to climate change, particularly agriculture, water resources, Himalayan region, coastal regions, health and disaster management
7. To mobilize domestic and new and additional funds from developed countries to implement the above mitigation and adaptation actions in view of the resource required and the resource gap
8. To build capacities, create domestic framework and international architecture for quick diffusion of cutting-edge climate technology in India and for joint collaborative R&D for such future technologies

[243] UNFCCC, “India Updated First Nationally Determined Contribution”, 2022.

176. **Two of India's targets submitted in its NDCs are close to being achieved currently.** As of 31st October 2024, 46.52% of the total cumulative power capacity in India (or 211.39 GW) was based on installed capacity from non-fossil fuel-based energy resources. Further, the emission intensity of its GDP has been reduced by 36% between 2005 and 2020.[244] An integrated approach to climate change and sustainability is also being adopted across several important economic policies and social welfare policies related to the building of social infrastructure. It is important to note that India's updated NDC does not set sector-specific mitigation targets, but India is committed to achieving and implementing various strategies to reduce emission intensity further, improve energy efficiency, and protect vulnerable sectors of the Indian economy.

Long-Term Low Carbon Development Strategies (LT-LEDS)

177. **Aligned with India's NDC targets and principles, the country has developed its comprehensive Long-Term Low-Emission Development Strategy (LT-LEDS) under Article 4.19 of the Paris Agreement to achieve net-zero emissions by 2070.** This strategy focuses on low-carbon development, adhering to the principles of equity and common but differentiated responsibilities and respective capabilities (CBDR-RC), while considering national circumstances. India officially submitted its LT-LEDS to the UNFCCC during COP27 in Sharm-el-Sheikh in 2022.

178. **The LT-LEDS emphasizes India's minimal historical contribution to the global carbon budget and its low annual per capita emissions.** As a developing nation with relatively low per capita energy consumption, India has substantial energy needs to drive its development agenda. This growth is vital not only for fostering economic progress but also for building climate resilience and addressing the risks and vulnerabilities posed by global warming.

The strategy includes seven broad strategies that seek to achieve all the targets submitted in its updated NDC as well as address important development concerns.[245] These are:

1. Low carbon development of electricity systems that can achieve developmental goals and aspirations
2. Creating and sustaining an integrated, efficient, inclusive, low-carbon transport system
3. Improving adaptation in urban design, energy and material efficiency in buildings, and sustainable urbanization
4. Moving towards an economy-wide decoupling of growth from emissions and development of an efficient, innovative low-emission industrial system
5. Enhancing Forest and vegetation cover consistent with socio-economic and ecological considerations
6. Addressing economic and financial aspects of India's economy that can provide a low-carbon development and Long-Term Transition to Net-Zero by 2070
7. Making efforts to promote carbon dioxide removal and other related engineering solutions to climate mitigation

Important qualifications to these strategies and targets within the LT-LEDS include:

1. Expanding renewables and strengthening the grid in the short to medium term while strengthening the electricity grid and enhancing its flexibility

[244] Ministry of Environment, Forest and Climate Change, "India: Fourth Biennial Update Report to the United Nations Framework Convention on Climate Change", 2024.
[245] UNFCCC, "India's Long-Term Low-Carbon Development Strategy", 2022.

2. Other technologies for low-emissions development such as a greater role for nuclear energy and enhance support for R&D into future technologies such as green hydrogen, fuel cells, and biofuels
3. Appropriate demand-side measures to meet the growing demand for energy services using less energy, while energy supply to the bulk of the population
4. Rational utilization of fossil fuel resources to transition to a state where the share of coal in installed capacity and supply of power will decline, but also recognizing that coal will be needed for power and energy, including grid stabilization, supply to industry and to guarantee India's energy security
5. Careful monitoring and assessment of the economic, technical and political feasibility of Carbon Capture Utilization and Storage (CCUS)
6. Assessing and addressing risks and vulnerabilities of economic and infrastructural development, improving governance capacities, improving access to adaptation finance, and ensuring that strategies are both "equitable and inclusive"
7. To channelise positive behavioural change leading to change in demand and consequent change in policies involving the Government and private sector as articulated by the 'Mission LiFE' programme launched by India in 2022

National Action Plan for Climate Change

179. **The National Action Plan on Climate Change (NAPCC), launched by the Government of India in 2008, serves as the country's overarching framework to address the challenges of climate change.** It comprises nine distinct missions to integrate sustainable development strategies with mitigation and adaptation efforts, each with its own budgetary allocations and other financing sources. The Government of India launched the National Action Plan on Climate Change (NAPCC) on 30th June 2008 outlining eight National Missions on climate change. These include:

- National Solar Mission
- National Mission for Enhanced Energy Efficiency
- National Mission on Sustainable Habitat
- National Water Mission
- National Mission for Sustaining the Himalayan Ecosystem
- National Mission for a Green India
- National Mission for Sustainable Agriculture
- National Mission on Strategic Knowledge for Climate Change

180. **The National Adaptation Fund on Climate Change (NAFCC) was established in 2015 with an initial outlay of INR 3,500 million to fund adaptation actions in State and Union Territories (UTs), that are not otherwise covered under the ongoing schemes/ programs.** NAFCC is implemented under project mode and thirty projects worth INR 8,474.80 million projects worth INR 8,474.80 million have been sanctioned in 27 States and UTs. These projects in agriculture, animal husbandry, water management, forestry and coastal resources management to enhance resilience and adaptive capacity at the national and state level, in terms of availability of improved water and food security, livelihoods, and ecosystem services. Detailed information on the approved projects, including concept notes and project document details, is hosted on the MoEF&CC website and can be accessed here.

Sectoral Actions to Promote Low-Carbon Development

181. In its **Nationally Determined Contributions (NDCs)** under the Paris Agreement and in its Long-Term Low Carbon Development Strategy (LT-LEDS), as well as in other communications to the United Nations Framework Convention on Climate Change (UNFCCC), India has pledged to undertake ambitious climate change mitigation efforts based on its access to a fair and equitable share of the global carbon budget.

182. **The government of India has consistently undertaken several initiatives to promote non-fossil fuel-based sources of energy.** Owing to these, India stands 4th globally in renewable energy installed capacity, 4th in wind power capacity and 5th in solar power capacity. Over the past decade, the installed solar energy capacity has surged from approximately 2.63 GW in March 2014 to around 92.12 GW in October 2024, marking an extraordinary increase of nearly 35 times. These achievements are in line with the updated Nationally Determined Contributions (NDCs) of India which includes, inter-alia, achieving about 50 per cent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.

183. **India has progressively continued decoupling economic growth from GHG emissions.** Between 2005 and 2020, India's gross domestic product (GDP) emission intensity reduced by 36%. It also reaffirms India's commitment to make a fair and equitable contribution to the global effort to mitigate climate change.

184. **India's forest and tree cover has consistently increased and currently stands at 25.17% of the total geographical area of the country.** From 2005 to 2021, an additional carbon sink of 2.29 billion tons of CO2 equivalent has been created.

185. The following sections provide an overview of key priorities, policies, plans, and schemes under the power, industry (with a focus on cement, aluminum, and iron and steel industries), transport (with a focus on road transportation), and agriculture sectors for low-carbon development. Information regarding the priority areas, schemes, and their achievements are taken from India's fourth Biannual Update Report to UNFCCC, submitted in December 2024, unless mentioned other.

Energy

186. **While coal remains the predominant source of electricity generation in India, RES (renewable energy sources) have grown.** Excluding hydro, RES has grown by over 10.94 % in generation and over 14.7 % in Installed Capacity in the year 2023-24. In its updated NDC, India has stated that it aims to have 50 per cent of its cumulative installed electric power capacity from non-fossil fuel sources by 2030, supported by technology transfer and affordable international financing, including from GCF. As of October 2024, the share of non-fossil fuel-based power generation capacity in the country is already at 46.52% (CEA, 2024). Given India's growing economy and electricity needs, the challenge of low-carbon development in the power sector is significant. These include ensuring energy access, affordability, reliability, and energy security.

187. **Additionally, the Government has taken several initiatives to incentivize higher penetration of non-fossil fuel sources in the total electricity mix in India.** This includes the waiver of inter-state transmission charges for solar and wind energy, Uniform Renewable Energy Tariff (URET), and Renewable Purchase Obligations (RPO) & Renewable Consumption Obligations (RCO). The Government of India has amended the Energy Conservation Act, 2001 (EC Act) wherein as per Section 14 (x), the Central Government has powers to specify the minimum share of consumption of non-fossil resources (renewable energy sources) by designated consumers as energy or feedstock and specify different shares of consumption for different types of non-fossil resources for different designated consumers.

188. **The National Solar Mission aims to position India as a global leader in solar energy by creating favorable policy conditions for rapid diffusion across the country.** Initially targeting 20 GW of total installed solar capacity by 2022, the mission had three phases: 1.4 GW in the first phase (2010-2013), 11-15 GW in the second phase (up to 2017), and 22 GW in the third phase (2017-2022). However, the government revised the

target to 100 GW by 2022 on July 1, 2015, with increased yearly targets from 2015 onwards. As of March 31, 2010, India had 161 MW of installed solar capacity, and by March 31, 2015, three months before the target revision, the country had achieved 3,744 MW of installed solar capacity.[246],[247]

Table 14. Interventions to support low-carbon development in the energy and power sector

S.No.	Scheme/ Initiative	Description	Implementing Agency	Achievements till date
1	Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY)	The DDUGJY, launched in December 2014 aims to strengthen the electricity distribution system. Activities include establishing new substations, upgrading old ones, and expanding power lines. Electrification efforts covered villages nationwide, with off-grid solutions where grid connectivity was impractical or expensive.	Ministry of Power, Government of India	By April 28, 2018, all inhabited unelectrified villages (as per Census of India, 2011) were electrified. 18,374 villages were electrified under the DDUGJY, including a total of 28.6 million households. The infrastructure created till date includes the installation of 693,181.52 km of 11 kV lines and 1,379,273 km of low-tension lines. Additionally, 1,665,047 Distribution Transformers (DTR) have been constructed.
2	Smart Meter National Program	EESL, through its JV IntelliSmart, is implementing a Smart Metering Program to enhance efficiencies for distribution utilities. Smart meters are pivotal for smart grid initiatives, crucial to meet challenges of the newly evolving energy mix for achieving uninterrupted 24x7 power supply. Connected via a web-based monitoring system, smart meters reduce commercial losses, boost revenues, and aid power sector reforms.	Energy Efficiency Services Limited (EESL), Ministry of Power, Government of India	As on date, EESL has installed over 35.75 lakh smart meters in Uttar Pradesh, Delhi, Haryana, Bihar, Rajasthan and Andaman under this programme. Apart from this, 3.03 Lac Smart Meters has been installed in the State of Assam.
3	Unnat Jyoti by Affordable LEDs for ALL (UJALA)	On January 5th, 2015, the Prime Minister of India launched the UJALA program, under which LED bulbs, LED Tube lights and Energy efficient fans are	Ministry of Power, Government of India	Till January 2024, over 368.6 million LED bulbs, 7.22 million LED tube lights and 2.36 million energy efficient fans (including over 55,000 brushless direct current (BLDC fans)) have

[246] The Solar Power Bill, 2017 (Government of India, 2017)
[247] Ibid.

		being sold to domestic consumers for replacement of conventional and inefficient variants.		been distributed by EESL across India. Between 2015 and 2024, this scheme is estimated to have led to annual energy savings of 48.39 billion kWh with avoided peak demand of 9,788 MW every year. Avoided emissions are estimated at 39.30-million-ton CO_2 per year during this period.
4	Thermal Power	The Ministry of Power implemented the Perform, Achieve and Trade (PAT) scheme, targeting energy efficiency in large industries, including Thermal Power Stations consuming over 30,000 tonnes annually. Covering 239 Thermal Power Stations with a capacity of around 197 GW, this scheme mandates reducing Net Heat Rate over three-year cycles, leading to decreased coal consumption and CO_2 emissions. Many TPPs have been upgraded to more efficient technologies, transitioning from subcritical to supercritical and ultra-supercritical technology, resulting in improved efficiency and reduced coal consumption and emissions.	Ministry of Power, Government of India	As of July 31, 2024, 94 units with a capacity of 65,290 MW (Supercritical/Ultra-supercritical) and 6 units with a capacity of 4,240 MW (Ultrasupercritical) have been commissioned. Additionally, about 104 units with a capacity of 8,279.92 MW of inefficient and old thermal power generation units were retired between January 2018 and April 2024. From 2011 to 2022, savings of 7.72 million tonnes of oil equivalent in energy and avoided emissions of about 28.744 million tonnes of CO_2 have been estimated due to these interventions.
5	Renewable Energy Sources (not including large hydro)	The Indian government has established a minimum share of consumption of non-fossil sources (renewable energy) by designated consumers as energy or feedstock and a different share of	Ministry of New and Renewable Energy, Government of India	The all-India level generation from renewable energy sources in 2023-24 includes 83,385.35 MUs from wind, 1,15,975.11MUs from solar, 3,417.19 MUs from biomass, and 9485.04 MUs from small hydro.

		consumption for different types of non-fossil sources for different designated consumers in respect of electricity distribution licensee and other designated consumers, to be in effect till March 2030 under the Energy Conservation Act, 2001. Along with this, the Government of India is implementing the Production Linked Incentive (PLI) Scheme across the nation, with an allocation of ₹24,000 crores for High Efficiency Solar PV Modules. Under the National Bioenergy Programme, the following bioenergy schemes are currently being implemented: Programme on Energy from Urban, Industrial and Agricultural Wastes/ Residues (Waste to Energy Programme), Scheme to Support Promotion of Manufacturing of Briquettes and Pellets and Biomass (Non-Bagasse) Based generation in Industries in the Country for the period from FY 2021-22 to 2025-26. Biogas Programme for installing small (1-25 cubic meters) and medium size biogas plants (above 25 m3		In 2024-25, 29.91% of total electricity is mandated to be purchased from renewable energy sources, increasing to 43.33% of total electricity from renewable energy sources till 2029-30. The target for wind energy is 3.48%, hydro is 1.33%, and distributed renewable energy is 4.5%. Under the National Bioenergy Programme, the achieved capacity includes 10.72 GW from biomass power and cogeneration projects, 604.5 MW from Waste to Energy projects, and biogas plants with 50.95 lakh small units and 361 medium units generating 11.5 MW off-grid power. The total avoided emissions from renewable energy sources in 2023-24 (up to December) amount to 135.61 million tons of CO_2, with 57.47 $MtCO_2$ from wind, 69.40 $MtCO_2$ from solar, 2.09 $MtCO_2$ from biomass, and 6.66 $MtCO_2$ from small hydro. This demonstrates a significant reduction in carbon emissions due to renewable energy generation.

		-2500 m3) for clean cooking purposes and decentralised power generation (off-grid) and thermal application. Government of India notified the Offshore Wind Energy Policy in October 2015. For the initial phase of developments, the Ministry of New and Renewable Energy has identified zones each off the coast of Gujarat and Tamil Nadu. The Offshore Wind Energy Lease Rules, 2023 were notified on 19th December 2023, under The Territorial Waters, Continental Shelf, Exclusive Economic Zones and Other Maritime Zones Act, 1976 (80 of 1976), to regulate the grant of lease of offshore areas for development of offshore wind energy projects.		
6	National Smart Grid Mission (NSGM)	The National Smart Grid Mission, under the Ministry of Power and with technical support from USAID's South Asia Regional Energy Partnership (SAREP), leads assessments for Smart Distribution cities. NSGM and SAREP teams have conducted visits to five distribution utilities and held kick-off meetings to initiate data collection.	Ministry of Power, Government of India	Two Smart Grid/Smart metering projects, funded by NSGM with Rs. 1160.1 million and Rs.348 million budgetary support by the Government of India, are nearing completion. As of November 2023, 1,69,330 smart meters have been deployed under these projects, with Rs. 313.2 million released to implementing utilities for milestone achievements. Under this scheme 1,78,522 Smart Consumer Metering has been sanctioned and 1,69,557 has been installed.
7	National Green Hydrogen Mission	The Ministry of New and Renewable Energy is executing the National Green Hydrogen Mission,	Ministry of New and Renewable Energy (MNRE), Government of	GAIL Limited has initiated India's maiden project of blending Hydrogen into the City Gas Distribution grid. Two percent hydrogen by volume is

		endorsed by the Union Cabinet on January 4, 2023, with a budget of ₹19,744 crore. The main objective is to establish India as the global hub for production, usage and export of Green Hydrogen and its derivatives. To complement this, CSIR has launched Hydrogen Mission for technology innovation and development. The overall goals of CSIR's Hydrogen Technology Mission are to demonstrate, integrate and showcase India's technology strengths across all three parts of H2 value chain as technology showcases in multiple cities in India – connecting to industry & society. The mission program envisages development of indigenized technologies at system level, enable capacity building, pursue path-breaking ideas to upgrade technologies and participate in technoeconomics/ road mapping/ testing activities to support the National Green Hydrogen Mission of India.	India Council of Scientific & Industrial Research, Ministry of Science and Technology, Government of India	blended into the CNG network, and 5% hydrogen by volume is blended into the PNG network at City Gas Station of Avantika Gas Limited (AGL), Indore, Madhya Pradesh. NTPC Limited has initiated blending of Green Hydrogen up to 8% (vol/vol) in PNG Network at NTPC Kawas Township, Surat, Gujarat from January 2023 Other PSUs have undertaken various projects such as: A. Introduction of Hydrogen-based Fuel-Cell Electric Vehicle (FCEV) Buses in Leh and Greater Noida by NTPC. B. Development of a 60-kW capacity hydrogen fuel cell bus by Oil India Limited, which is a hybrid of electric drive and a fuel cell. C. Establishment of demonstration pilot plants for Green Hydrogen production through water electrolysis using solar power, biomass oxy steam gasification, and CBG reforming to refuel 15 Hydrogen Fuel Cell buses by Indian Oil. By the year 2030, the mission aims to achieve a production capacity of at least 5 million metric tonnes (MMT) of green hydrogen annually with an associated renewable energy capacity of about 125 GW, 60-100 GW electrolyser capacity and about 1 lakh crore of Import saving. This initiative is expected to result in the avoidance of 50 million metric

				tonnes (MMT) of CO_2 emissions annually

Industry

189. **The industrial sector is a cornerstone of the Indian economy, contributing significantly to the country's gross value added.** It represents 31% of India's GDP and employs over 121 million people. In the year 2022-23, the industrial sector experienced a growth of 6.7%, with manufacturing emerging as a key driver of economic expansion. Key sectors such as automotive, engineering, cement, textiles, steel, chemicals, pharmaceuticals, and consumer durables are pivotal in this growth trajectory.

190. **In FY 2022-23, the industrial sector was the larger consumer of energy, with iron and steel accounting for the most energy use within the category.** The total final energy consumption by the industrial sector in India was 270,000 ktoe (P), making it the largest consumer of energy in the country, accounting for 48.95% of the total final energy consumption. The most energy-intensive sub-sector within the industrial sector was the Iron and Steel sector, accounting for 15.15% of industrial energy use, followed by chemicals and petrochemicals at 4.56%, and construction at 1.80%.

191. **In recent years, there has been a notable increase in the emphasis on energy efficiency within the industrial sector through initiatives like the Perform, Achieve and Trade (PAT) scheme.** PAT serves as a regulatory tool aimed at reducing Specific Energy Consumption in energy-intensive industries, employing a market-based approach to enhance cost-effectiveness through the certification and trading of excess energy savings certificates (ESCerts). Designated Consumers (DCs) in key sectors are identified and notified under the scheme, mandated to appoint energy managers, submit annual energy consumption reports, and conduct regular energy audits. Additionally, a new Advanced Industrial Technology Demonstration Centre (AITDC), named UTPRERAK was established at NPTI Badarpur in June 2023. It features non-functional models of energy efficiency technologies in sectors like Cement, Iron & Steel, Pulp & Paper, Textile, and Chlor-Alkali.

Table 15. Interventions to support low-carbon development in the industry sector

S.No.	Scheme/ Initiative	Description	Implementing Agency	Achievements till date
1	PAT for cement industry	Since its inception in 2012, the Cement industry has consistently been part of the PAT cycles, with new Designated Consumers (DCs) joining each rolling cycle. Currently, the industry's top-performing plant consumes 19% less energy than the global average, and approximately 40% of the total installed capacity is equipped with the latest technology and equipment and is less than 10 years old. Key emission reduction measures implemented by the	Ministry of Power and Bureau of Energy Efficiency, Government of India	In all cycles except PAT Cycle IV (2018-19 to 2021-22), the industry exceeded its reduction targets. During PAT Cycle I (2012-15), it surpassed the target by 82%, while in PAT Cycles II (2016-17 to 2018-19) and III (2017-18 to 2019-20), it exceeded by 39% and 66%, respectively. In PAT Cycle V (2019-20 to 2021-22), it surpassed targets by 76%. However, in PAT Cycle IV (2018-19 to 2021-22), it fell short of the targeted energy savings by 50%. Over all the five cycles, there has been a cumulative energy savings of 3.35 Mtoe. The avoided emissions in

		industry include: • Increased utilization of alternative fuels and raw materials • Installation of Waste Heat Recovery Systems (WHRS) from pre-heater outlets • Installation of Kiln shell radiation recovery systems • Calcium looping technology for carbon capture • Blending of fly ash/ slag residue		cycles I-V have been 4.34, 5.45, 0.339, 0.008, and 0.61 MtCO2/year, respectively.
2	PAT for iron and steel industry	The PAT scheme has covered upto 204 Iron & steel plants as Designated Consumers (DCs) during the cycles I-VII so far.	Ministry of Power and Bureau of Energy Efficiency, Government of India	In all cycles, the industry exceeded its targets. During PAT Cycle I (2012-15), II (2016-17 to 2018-19), III (2017-18 to 2019-20), IV (2018-19 to 2021-22) and V (2019-20 to 2021-22), it surpassed targets by 41%, 25%, 25%, 85% and 56% respectively. Over the five cycles, there has been a cumulative energy savings of 6.14 Mtoe. The avoided emissions in cycles I-V have been 6.51, 11.85, 1.69, 1.41 and 1.04 MtCO2/year, respectively.
3	PAT for aluminium industry	The PAT scheme has covered up to 14 aluminium plants as Designated Consumers (DCs) during cycles I-VII.	Ministry of Power and Bureau of Energy Efficiency, Government of India	In all cycles, the industry has exceeded its targets. During PAT Cycle I (2012-15), II (2016-17 to 2018-19), III (2017-18 to 2019-20) and V (2019-20 to 2021-22), it surpassed targets by 60%, 167%, 46% and 20% respectively. Over the five cycles, there has been a cumulative energy savings of 2.13 Mtoe. The avoided emissions in these cycles have been 3.1, 4.2, 0.35 and 0.35 MtCO2/ year, respectively
4	Measures taken by National Aluminium	NALCO has introduced low-carbon technologies in the production process that contribute to reducing emissions. They include, (1)	National Aluminium Company (NALCO)	Graphitization of cathode blocks used in smelters has led to reduction of specific electrical energy consumption to 55 kWh/Mt.

	Company (NALCO)	Graphitization of cathode blocks used in smelters has led to reduction of specific electrical energy consumption, (2) In its captive power plant, NALCO has introduced chemical cleaning of condensers and revamping of preheaters in boilers, leading to a decrease in specific coal consumption, and, (3) Installation of anode slot cutting machine has led to the reduction of specific DC energy consumption.		Installation of anode slot cutting machine has led to the reduction of specific DC energy consumption to 140 kWh/Mt of hot metal. This is estimated to avoid up to 0.031 million tonnes of CO_2 per year.

Transport

192. **India is one of the world's most rapidly expanding economies, which in turn has significantly increased the need for efficient transportation of goods and people.** In this context, the transportation sector becomes a fundamental element of India's economic growth, contributing to its socio-economic development and addressing the increased mobility needs stemming from rapid urbanization.

193. **There is an increasing recognition of the importance of managing demand alongside the adoption of innovative technologies.** Innovation in technologies includes the surge in e-mobility for land-based transportation, along with the development of advanced biofuels and hydrogen-based fuels for maritime and aerial transport. Low carbon development of land-based, long-haul, heavy-duty vehicles through battery-electric vehicles (including Electric Road Systems) and, in certain scenarios, is complemented by hydrogen and biofuel-based solutions (with medium confidence) is being explored and can become viable in the future. On the demand side, modifications in urban structures, behavioral initiatives, circular and shared economies, as well as digitalization, are facilitating systemic shifts that decrease the demand for transport services or promote the usage of more efficient modes of transportation.

194. ***Electric Vehicles and Related Infrastructure.*** In India, the adoption of EVs is growing rapidly. The country's EV market is expected to grow at a compound annual growth rate (CAGR) of 49% from 2022 to 2030, with estimated annual sales of over one crore units in 2030.[248] To achieve ambitious targets, the Indian government has implemented various policy interventions through the Union Budget of 2023-2024 and the Ministry of Heavy Industries. The Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) Scheme, launched in 2015, aims to reduce fossil fuel dependency. It has a budget of Rs. 10,000 crore and a 5-year timeline. The Production Linked Incentive (PLI) Scheme for the Automotive Sector and the PLI Scheme for a National Programme on Advanced Chemistry Cell (ACC) Battery Storage were introduced to boost manufacturing and attract investments. As of July 2023, 8,32,824 vehicles have been sold around FAME-II.[249]

[248] Government's EV Policies Driving India's Green Revolution (Government of India, 2023)
[249] Fame India Scheme (Government of India, 2023)

To further incentivize EV adoption, the government extended customs duty exemption to the import of goods required for the manufacturing of lithium batteries for EVs, reduced GST on electric vehicles and charging stations, provided green license plates, waived road tax on EVs, and issued guidelines for expanding the Public Electric Vehicle Charging Infrastructure. These measures aim to accelerate India's transition to green mobility, contributing to the target of achieving net zero emissions by 2070.[250]

The National Mission on Transformative Mobility and Battery Storage, launched by the Indian government in 2019, focuses on establishing large-scale, export-competitive integrated batteries and cell-manufacturing plants in the country. However, there is a notable gap in addressing the sustainable end-of-life management of batteries, particularly lithium-ion batteries used in electric vehicles (EVs). With the expected surge in demand for battery recycling in the coming years, especially as EV adoption increases, it is anticipated that EV batteries will constitute 80% of the lithium-ion battery market by 2030. This presents an opportunity for the government to proactively plan and implement mechanisms for repurposing batteries for secondary applications or recycling them to recover metals.[251]

195. ***Compressed Biogas.*** The Government of India introduced the National Policy on Biofuels in 2018 to increase their use in the energy and transportation sectors over the next decade. The policy aims to achieve various benefits, including reducing crude and LNG imports, promoting domestic feedstock utilization, contributing to national energy security, mitigating climate change, and controlling pollution. As part of this initiative, the oil industry, particularly Hindustan Petroleum Corporation Limited (HPCL), has undertaken various biofuel projects, including Compressed Biogas (CBG) projects under the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative. The SATAT initiative aims to produce 15 million metric tons of CBG by 2023-24 from 5000 CBG plants.[252]

The process involves generating CBG from waste and biomass sources through anaerobic decomposition. The purified CBG, with more than 90% methane content, is similar to Compressed Natural Gas (CNG) and can be utilized as a green renewable automotive fuel, replacing CNG in various sectors. Oil Marketing Companies (OMCs) have invited expressions of interest (EOIs) from eligible entrepreneurs to set up CBG plants and supply CBG to OMCs. In the fiscal year 2020-21, HPCL issued Letters of Intent (LOIs) for setting up 100 new CBG plants with a total capacity of 635 tonnes per day, bringing the cumulative to 151 LOIs with a capacity of 841 tonnes per day. The CBG produced at these plants will be transported to OMCs' retail outlet networks for marketing as a green transport fuel alternative.[253]

The Biogas Programme (Phase-I) for FY 2021-22 to 2025-26 in India aims to leverage the country's substantial livestock population for setting up biogas plants. With 535.78 million livestock, including 302 million bovines, the program is designed to benefit farmers and contribute to India's GDP. Biogas, comprising mainly methane, is utilized for clean cooking, lighting, power generation, and as a substitute for diesel. The program focuses on disseminating biogas technology, offering direct and collateral benefits to farmers.[254]

Objectives of the Biogas Programme include promoting clean cooking fuel, lighting, and meeting power needs, leading to greenhouse gas reduction, improved sanitation, women empowerment, and rural employment creation. Additionally, the program aims to produce organic-enriched bio-manure from the digested slurry, serving as a natural fertilizer to reduce dependence on chemical fertilizers. Eligibility criteria for small biogas plant installation include land ownership, availability of cow dung/feedstock, regular water supply, and financial

[250] Ibid.
[251] Ibid.
[252] Jumpstart Biogas in India (GERMI, 2022)
[253] Biogas Programme (Government of India, 2023)
[254] Ibid.

capacity for the beneficiary's investment. The government announced compulsory blending of compressed biogas which is extracted from municipal and agriculture waste in natural gas to cut reliance on imports.[255]

India has a history of promoting biogas technology, particularly in rural areas, through initiatives like the National Biogas and Manure Management Programme (NBMMP) launched in 1981. Despite subsidies and schemes, the biogas sector has not flourished as expected. The market remains scattered and rural-oriented, lacking large-scale, professionally managed, investor-owned biogas plants. India can seek guidance from Germany's model, which introduced appropriate tariffs and reduced risks to attract investors. The transition from a government-driven to an incentive-supported, developer-driven market, as seen in wind and solar energy, should be prioritized. Like bioethanol, India should explore the possibility of mixing a certain percentage of biogas into compressed natural gas or even the gas grid. This policy can give incentives to developers who wish to produce gas instead of power.[256]

Table 16. Interventions to support low-carbon development in the transportation sector (with focus on road transport)

S.No.	Scheme/ Initiative	Description	Implementing Agency	Achievements till date
1	Emission Standards and Auto Fuel Policy of 2003	The Auto Fuel Policy of 2003 aimed to curtail vehicular emissions through stringent fuel quality standards and efficient fuel supply measures. Significant amendments were made to The Central Motor Vehicles Rules, 1989, by 2018, requiring vehicles manufactured before April 1, 2020, to meet BS-IV standards, notable for reducing sulphur emissions by 80%.	Ministry of Petroleum & Natural Gas, Ministry of Urban Development, Ministry of Road transport and highways	Replacing diesel with CNG vehicles has resulted in avoided emissions of about 84% for CO emissions, 58% for NOx , and 97% for PM.
2	Corporate Average Fuel Economy (CAFE)	Introduced in FY 2017-18 and the second phase of norms was started in FY 2022- 23, CAFE Norms for passenger vehicles aim to reduce overall fuel consumption. These norms, coupled with standards for heavy-duty and light commercial vehicles introduced in 2017 and 2019, respectively,	Ministry of Road Transport and Highways, Government of India	For FY 2019-20 to 2022-23 the collective energy savings amount to 1.88 Mtoe and the corresponding avoided emissions are estimated at 4.41 MtCO2

[255] Mandatory Biogas Blending (Economic Times of India, 2023)
[256] Compressed Biogas (Hindustan Petroleum, 2023)

		have led to significant avoidance of emissions		
3	Green National Highways Corridor Project (GNHCP)	This project targets economic policy, human development, urban and rural development, and environmental management. The project's success indicators include enhancing natural resource efficiency, reducing construction emissions, and implementing green technologies over 2,500 kilometres of highways.	National Highways Authority of India (NHAI), Ministry of Road Transport and Highways, Government of India	781 kilometres of green Highways is proposed to be constructed and an MOU has been signed between GOI and World Bank. INR 1000 crore per year will be available in the annual budget for plantation purpose. Rs. 7,662.47 crore is loan assistance from World Bank.
4	National Electric Mobility Mission Plan (NEMMP)	Launched in 2013, the National Electric Mobility Mission Plan (NEMMP) 2020 aims to achieve national fuel security by promoting hybrid and electric vehicles in the country. Government aims to provide fiscal and monetary incentives to kick start this nascent technology.	Ministry of Heavy Industries, National Automotive Board, Government of India	The policy aims to deploy 400,000 passenger battery-powered electric vehicles (BEVs) by 2020 to reduce oil imports and CO2 emissions. It sets an ambitious goal of achieving 6-7 million hybrid and electric vehicle sales annually from 2020 onward. The policy envisages to save a total of 9500 million litre of crude oil.
5	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME)	FAME India Scheme incentivizes the adoption of electric vehicles across various segments. Phase-II of FAME, launched in April 2019 with a budget of INR 10,000 Crores, supports the electrification of public and shared transport, including subsidizing e-buses, e-three-wheelers, e-passenger cars, and e-two-wheelers, alongside developing charging infrastructure to alleviate range anxiety among electric vehicle users.	Ministry of Heavy Industries, National Automotive Board, Government of India	Under the FAME-I scheme, 465 buses were sanctioned to various cities/ states. It promoted about 2,80,000 hybrid and EV sales. Phase-II aims to generate demand by way of supporting 7000 e-Buses, 5 lakh e-3 Wheelers, 55000 e-4 Wheeler Passenger Cars (including Strong Hybrid) and 10 lakh e-2 Wheelers. The Department of Heavy Industry approved 6315 e-buses, with supply orders issued for 3738 as of December 9, 2022. Of these, 2435 e-buses have been deployed. In Phase II, the Ministry approved 2877 EV charging stations, with

		FAME-I encouraged electric and hybrid vehicle purchase by providing financial support. FAME-II focused on electrification of public transport infrastructure and charging. EVs sold through 2030 could cumulatively save 474 MTOE worth INR 15 lakh crore and generate net CO2 savings of 846 million tons over their operational lifetime.		letters of award issued for 1822 as of December 9, 2022. Of these, 83 are commissioned and operational. Additionally, 1576 charging stations across 9 expressways and 16 highways were sanctioned under the FAME India Scheme Phase II. In the time period between 2018-19 and 2021-22 the collective energy savings amount to 0.142 Mtoe and the corresponding avoided emissions are about 0.432 MtCO2 due to the implementation of this scheme.
6	Bus Rapid Transit System (BRTS)	Implemented under the Jawaharlal Nehru Urban Renewal Mission and the National Urban Transport Policy of 2006, BRTS aims to enhance bus transport by funding buses, creating dedicated lanes, and expanding CNG bus fleets. Operational in 11 cities including Ahmedabad, Bhopal, Hubli-Dharwad, Surat, Visakhapatnam, and Indore, Ahmedabad's BRTS achieved a silver rating in 2013, while HubliDharwad's system, a recent addition, notably improved local mobility, attracting a daily ridership of 90,000 passengers	Ministry of Housing and Urban Affairs, Government of India	For the period of 2006-2015, the collective avoided emissions are estimated at 0.039 MtCO2.
7	Ethanol Blended Petrol Programme	The Ethanol Blended Petrol program aims to boost biofuel usage in India by blending different types of biofuels with petrol. The "National Policy on Biofuels" of 2018 and 2022 amendment, set targets to achieve 20% ethanol blending in petrol and 5% biodiesel blending in diesel by 2030. Efforts have	Ministry of Petroleum and Natural Gas, GOI	The target of 10% ethanol blending set in the 'Roadmap for Ethanol Blending in India 2020-25' for ESY 2021-22 has already been achieved and Public Sector Oil Marketing Companies (OMCs) have started selling E20 (20% ethanol blended) petrol nationwide. One Crore litre of ethanol blended petrol can save around 20,000 tons of carbon dioxide (CO2) emission.

		intensified, and it's projected that 20% ethanol blending in petrol will be reached by 2025-26.		Greenhouse gas emissions due to the EBP Programme were reduced by 318.2 lakh tons during 2014 to November 2022.

Agriculture

196. **The agriculture sector in India plays a crucial role in ensuring food and nutritional security and provides livelihood support to about 42.3 per cent of the population.** The sector also contributes to 14.37 per cent of the total GHG emissions in India. The threat of climate change poses a challenge for sustainable agricultural growth and hence this sector must become resilient to increasing climatic variability and change.

197. **While India's voluntary declaration excludes mitigation in the agricultural sector, the government has been taking steps to reduce the sector's carbon intensity given its scale of operations.** Agriculture in India, as in many developing countries, is characterized by smallholder farming. The adaptation burden in this sector is currently, and expected to be, very high and smallholder farmers have not contributed to greenhouse gas emissions responsible for warming so far. The Indian government has therefore focused on and implemented numerous measures to enhance the sector's resilience to climate change and improve its capacity to adapt to climatic variability. Nevertheless, given the scale of agricultural activities in the country, the Government of India has also adopted several initiatives to reduce the carbon intensity of agricultural production while sustaining its economic contribution through sustainable practices and increased productivity.

Table 17. Interventions to support low-carbon and climate-resilient development in the agriculture sector

S.No.	Scheme/ Initiative	Description	Implementing Agency	Achievements till date
1	Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) – Per Drop More Crop (PMKSY-PDMC)	PMKSY aims to improve on-farm water use efficiency, enhance the adoption of precision irrigation and other water saving technologies (more crop per drop) and enhance the recharge of aquifers. PMKSY- PDMC mainly focuses on enhancing water use efficiency at farm level through precision/micro-irrigation (drip and sprinkler irrigation) systems. Micro-irrigation helps in water saving as well as reduced fertilizer usage through fertigation, labour expenses, other input costs and overall income enhancement of farmers. The PDMC also promotes activities such as micro level water harvesting/ storage viz., farm pond, secondary storage structure, construction of tube wells / bore wells (shallow / medium), restoration / renovation of small tank, recharge of defunct bore well etc. These activities are to be mandatorily linked with micro-	Ministry of Agriculture & Farmers Welfare	The Department of Agriculture & Farmers Welfare is implementing centrally sponsored scheme of PDMC component of PMKSY in the country from 2015-16 to 2021-22. From the year 2022-23, the PDMC is being implemented under the Rashtriya Krishi Vikas Yojana (RKVY). So far, a total amount of Rs. 16815.66 crore has been released for the micro-irrigation scheme, covering an area of 70.04 lakh hectares. The assistance for installation of micro-irrigation systems is up to 5 hectares per beneficiary. The area covered under drip and sprinkler irrigation was 23.84 and 29.02 lakh ha, respectively during 2019-24. The cumulative emission reduction was amounted to 555.3 MtCO2eq from 2019- 20 to 2023-24.

		irrigation to make potential use of the available water for higher water use efficiency.		
2	Solarization of Agriculture - Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan (PM-KUSUM)	M-KUSUM scheme aims for dedieselization of farm sector, providing water and energy security to farmers, increasing the income of farmers, and curbing environmental pollution. The scheme has three components targeted to achieve solar power capacity addition of 34.8 GW by 31.3.2026 with total central financial support of Rs. 34,422 Cr. Component A involves setting up of 10,000 MW of decentralized ground/ stilt mounted solar power plants on barren/fallow/pasture/marshy/cultivable land of farmers. Installation of 14 lakh stand-alone solar pumps in off-grid areas through component B and solarization of 35 lakh grid connected agriculture pumps through individual pump solarization and feeder level solarization through component C. The scheme involves replacement of diesel pumps with solar pumps and panels that would result in daytime reliable power for irrigation, enhancing farmers income by selling surplus solar power at pre-determined rates to DISCOMS and reducing electricity subsidy burden of the state/DISCOMs.	Ministry of New and Renewable Energy	The scheme has been launched in 2019 and was extended till 2026. The central financial assistance is now increased from installation of 7.5 HP capacity solar pumps to 15 HP capacity solar pumps to the individual farmers in the Northeastern States, Hilly States/UTs and Islands UTs, and for each farmer in the cluster/ community irrigation projects in high water table areas in all the States/ UTs. Three solar integrated micro-irrigation projects at Precision Farming Development Centres (PFDCs) namely Ludhiana, Bhopal and Leh are being implemented by NCPAH under the PMKSY-PDMC. A project for the establishment of demonstration units on micro-irrigation systems across 190 Krishi Vigyan Kendras has been approved by the extension division of ICAR under PMKSY-PDMC. Number of solar pumps installed under component B & C were 3,14,435 and 11,778, respectively during 2019-24. The cumulative CO2 emission reduction of 0.79 MtCO2eq was achieved during the period 2019-24 from standalone solar powered agriculture pumps installed under component B.
3	Agriculture Demand Side Management (AgDSM)	The AgDSM initiative encompasses strategies and policies designed to alter power consumption behaviors among consumers, particularly farmers. All AgDSM projects in India prioritize the substitution of inefficient agricultural pump sets with BEE star-rated	Bureau of Energy Efficiency, Ministry of Power	As on 31st March 2023, 81,180 agricultural pumps have been installed. An emission reduction of 0.68 MtCO2eq was achieved between 2019-2023.

		energyefficient models, while also promoting awareness about the benefits of using energy efficient pumps. In addition to increased energy usage, the current pump sets indirectly contribute to groundwater wastage, as farmers presently lack incentives to monitor or adjust the pump operation based on the actual water demand for irrigating crops, wherein AgDSM emerges as an appealing choice to curb both water and energy wastage in the agricultural sector. This program ensures energy efficiency in agricultural demand management by reducing overall power consumption, enhancing groundwater extraction efficiency, alleviating subsidy burdens on state utilities, and steering clear of additional investments in power plants. Energy Efficiency Services Limited (EESL) under the aegis AgDSM, is implementing the Energy Efficient Pump Program to distribute BEE 5-star energy efficient agricultural pumps and ensures a minimum of 30% reduction in energy consumption with smart control panels which can be remotely operated to enhance the ease of operation of pumps by the farmers.		
4	Avoiding crop residue burning - Sub-Mission on Agriculture Mechanization (SMAM)	To support the efforts of the Governments of Punjab, Haryana, Uttar Pradesh and NCT of Delhi in addressing the air pollution caused due to stubble burning and to subsidize machinery required for in-situ management of crop residue, a Central Sector Scheme on Crop Residue Management (CRM) was implemented from 2018-19. The scheme promotes the usage of machines such as super straw management systems, happy seeder, super seeder, smart seeder, zero till seed cum fertilizer drill, mulcher, paddy straw chopper, hydraulically reversible mould board plough, crop reapers and reaper binders for in-situ management of crop residue and balers & rakes which are used for	Ministry of Agriculture & Farmers Welfare	During the period from 2018-19 to 2023-24, Rs. 3333.1 crores were released and distributed more than 2.47 lakh machines to the individual farmers and Custom Hiring Centres (CHCs) and more than 42000 CHCs were established in the 4 States, which also include more than 4500 balers & rakes. The number of burning events detected between 15 September to 29 October during 2021, 2022 and 2023 were 11461, 13964 and 6391, respectively i.e., 44.3% and 54.2% reduction in number of burning events were observed in the year 2023 as compared to 2021 and 2022, respectively. Emission reduction of 1.447 MtCO2eq was achieved during

		straw collection in the form of bales for other ex-situ uses of straw.		2019-24 by avoiding crop residue burning using in-situ crop residue management machines.
5	Crop Diversification Programme (CDP)	The goal of this programme is to divert the cultivation area from water-intensive paddy to alternative crops such as pulses, oilseeds, coarse/nutri cereals, cotton, and agroforestry, with the objective of addressing the issues of declining soil fertility and depleting water table in these states. Under CDP, for replacing paddy crop, assistance is provided for four major interventions viz., alternate crop demonstrations, farm mechanization and value addition, site-specific activities and contingency for awareness, training, monitoring, etc. This enables the reduction of CH4 emissions associated with paddy production.	Ministry of Agriculture & Farmers Welfare	The Department of Agriculture & Farmers Welfare (DA&FW) is already implementing a Crop Diversification Programme, a sub-scheme of the Rashtriya Krishi Vikas Yojana (RKVY) in the traditional green revolution states, namely Punjab, Haryana, and Western Uttar Pradesh since 2013-14. The area diversified from paddy to alternate crops was 1,02,936 ha during 2019-24. The mitigation potential through CDP was 0.214 MtCO2eq during 2019-24.
6	Rashtriya Gokul Mission	The scheme is being implemented for development and conservation of indigenous bovine breeds since December 2014. The scheme is important in enhancing milk production and productivity of bovines to meet growing demand of milk and making dairying more remunerative to the rural farmers of the country.	Ministry of Fisheries, Animal Husbandry and Dairying	The scheme is also continued under umbrella scheme Rashtriya Pashudhan Vikas Yojna from 2021 to 2026 with a budget outlay of Rs. 2400 crore. Number of elite indigenous cows and buffaloes in milk as on 2023-24 are 487.2 and 243.6 lakhs, respectively. The reduction in emissions attained by producing female calves having high genetic merit germplasm for enhancing milk production and productivity for the period 2019-24 was computed to be 2.086 MtCO2eq.

198. **In addition to these efforts, India has introduced various support schemes aimed at bolstering the competitiveness of Indian manufacturers in the renewable energy sector as well.** Initiatives such as Production Linked Incentive schemes, especially for emerging markets like Green Hydrogen and Battery Manufacturing play a crucial role in attracting investment, fostering innovation, and driving growth in renewable energy infrastructure. Moreover, India's ambitious government targets and commitments towards renewable energy deployment have further fueled investor interest. The government's goal of achieving 500 GW of RE capacity by 2030, along with initiatives like the International Solar Alliance (ISA), has positioned India as a frontrunner in the global renewable energy landscape. This ambitious vision not only drives market growth but also creates a conducive environment for innovation, technology transfer, and sustainable development.

199. **The Green Growth announcement in Budget 2023 by Hon'ble Finance Minister Shrimati Nirmala Sitharaman on 1st February 2024 unveiled several key initiatives for powering the clean energy transition.** These include the Green Hydrogen Mission, which allocated Rs 19,700 crores to facilitate the economy's low-

carbon transition, alongside Rs 3,500 crore for priority capital investments towards energy transition and net-zero objectives. The budget also supports Battery Energy Storage Systems with a 4,000 MWH capacity through Viability Gap Funding and allocates resources for the construction of an Inter-state transmission system for the evacuation and grid integration of 13 GW renewable energy from Ladakh, with an investment of Rs. 20,700 crores including central support of Rs. 8,300 crores. Additionally, the budget includes plans for 500 new 'waste to wealth' plants under the GOBARdhan scheme and promotes coastal shipping as an energy-efficient and cost-effective mode of transport through PPP mode with viability gap funding, benefiting both passengers and freight.[257] In 2024, the Union Cabinet approved the Viability Gap Funding (VGF) scheme with a total outlay of Rs.7453 crore for offshore wind energy projects, including Rs.6853 crore for 1 GW installation in Gujarat and Tamil Nadu and Rs.600 crore for port upgrades. This scheme aims to implement the National Offshore Wind Energy Policy by reducing power costs from these projects, making them viable for DISCOMs, and ensuring private developers establish the projects while Power Grid Corporation of India Ltd handles the power infrastructure.[258] The Ministry of New and Renewable Energy will oversee coordination for successful implementation.

[257] budget_speech.pdf (indiabudget.gov.in)
[258] Cabinet approves Viability Gap Funding (VGF) scheme for implementation of Offshore Wind Energy Projects | Prime Minister of India (pmindia.gov.in)

Appendix 3 – Programs and interventions complimentary to IGFF

Name of GCF interventions	Co-Financiers, Accredited Entities, and Executing Entities	Key Areas of Coverage, Outcomes, and Activities
SIDBI **Financing Mitigation and Adaptation Projects (FMAP) in Indian MSMEs** **(FP241)**	**Accredited Entity:** Small Industries Development Bank of India (SIDBI)	Through GCF co-financing (USD 200 million in loans and USD 16 million for technical assistance) SIDBI is supporting the MSME sector (a significant emitter of greenhouse gases) in financing mitigation and adaptation interventions. The sector is also highly exposed to climate hazards, exacerbated by the low resilience of small business owners to extreme weather events. Barriers such as a lack of affordable financing and limited technical know-how severely restrict the urgent adoption of low emission and climate-resilient practices among Indian MSMEs.
Green Guarantee Company ("GGC") (FP197)	**Accredited entity** MUFG Bank, Ltd, **Executing Entity:** GGC **Co-Financing:** FCDO	This program addresses the issue of insufficient climate financing from developed to developing nations by reducing risks for private sector investments in mitigation and adaptation projects. GGC provides developing countries access to global capital markets. GCF, as the founding equity shareholder, will offer initial capital to encourage participation from private and institutional investors. Adaptation: the intervention is projected to deliver immense financial and direct benefit directly in the form of guarantees (to bonds and loans) for climate change adaptation and will leverage in catalytic private finance for adaptation and mitigation investments over 20 years. **Outcome:** - Mitigation: shift to low-emission sustainable development pathways with a corresponding mitigation impact (GHG emissions reduced) - Adaptation: Increased climate-resilient sustainable developmental impact and improved adaptative capacity are achieved in the supported projects that successfully contribute to the NDC of selected countries - Enabling Environment: Market transformation by providing a de-risking mechanism that leads to an increase in green bonds and loans being issued by developing countries. This includes borrowers accessing an improved credit rating that closes the climate finance gap and drives financial sector development and stability. - Enabling Environment: Increased access to effective knowledge generation and learning processes into the use of guarantees to accelerate and scale-up private sector capital for climate mitigation and adaptation investments

<table>
<tr>
<td>FP190

Climate Investor Two</td>
<td>Accredited Entity: Nederlandse Financierings-Maatschappij voor Ontwikkelingslanden (FMO)

Executing Entity:

Nederlandse Financierings-Maatschappij voor Ontwikkelingslanden (FMO)

Co-Financier:

Other Investors</td>
<td>The Climate Investor Two (CI2) project focuses on addressing critical issues related to the water cycle and its connection to the global climate crisis. Here's a summarized overview of the key points regarding the project's area of coverage:

Water Cycle and Climate Crisis: The project highlights the significance of the water cycle in the context of the global climate crisis. Improper management of water resources can lead to substantial carbon emissions, particularly through untreated waste and wastewater, contributing to 7% of global greenhouse gas emissions. On the other hand, coastal ecosystems have the potential to act as powerful "carbon sinks," helping mitigate emissions.
Threat to Livelihoods: The imbalance between the water cycle and the climate poses a threat to livelihoods, especially in developing nations. Growing economies and populations are reducing freshwater availability, risking over USD 6 trillion of GDP in developing nations. Access to clean water and proper sanitation is lacking for millions of people, and even the oceans are under threat from pollution and rising sea levels.
Climate-Resilient Infrastructure: There is a clear need for climate-resilient infrastructure to mitigate these risks, especially in developing countries. Inadequate water and sanitation infrastructure are linked to 80% of all illnesses in the developing world, and climate-induced water shortages could significantly impact developing countries' GDP.
CI2's Mission: Climate Investor Two (CI2) aims to develop and construct climate-resilient infrastructure projects in developing countries, focusing on the water, sanitation, and ocean sectors. The goal is to reduce greenhouse gas emissions and increase resilience to climate change. CI2 employs an innovative financing approach, involving two interconnected funds, to support projects at different stages of the lifecycle.

Outcomes:

- Improved wastewater capacity treatment

- Improved access to water (m3/day)

- Improved renewable energy capacity and generation</td>
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FP186 **India E-Mobility Financing Program**	**Accredited Entity:** Macquarie Alternative Assets Management Limited **Executing entity:** - Singapore LP - Macquarie Group entity that will set up GP - Singapore Manager - SG Master Co. - SG Co - Macquarie India Advisory Company (IAC) - Platform	The proposed Programme aims to promote the electrification of India's transport sector, with a focus on accelerating the adoption of electric vehicles (EVs) and related infrastructure while phasing out traditional Internal Combustion Engine (ICE) vehicles. Its key objectives include: 1. Providing tailored financial solutions to EV owners and operators. 2. Supporting ancillary areas of the EV ecosystem, such as charging infrastructure. 3. Addressing user concerns like high upfront costs and reliability. 4. Facilitating the development of the EV market through investments and partnerships. 5. Improving the efficiency of EV services. 6. Enhancing the long-term cost competitiveness of EVs. 7. Mobilizing significant institutional capital into India's EV sector. The Programme seeks USD 200 million from the Green Climate Fund (GCF) and USD 205 million from commercial investors to establish an India-focused E-mobility Financing Platform. Managed by Macquarie Asset Management (MAM), the Platform aims to access debt markets for further expansion. The Programme addresses key barriers to EV adoption, aligns with national and international climate goals, and plans to reduce around 9.5 million tons of CO2 emissions. It also contributes to India's energy security, job creation, gender empowerment, and environmental sustainability. The executing entities adhere to strong governance and climate impact standards. **Outcomes:** - Enabling environment for EV market established - Increased penetration of electric vehicles in India
FP164 **Green Growth Equity Fund**	**Accredited Entity:** Nederlandse Financierings-Maatschappij voor Ontwikkelingslanden (FMO) **Executing Entity:** - Investment Manager of the Domestic Fund	The proposed program aims to accelerate green infrastructure projects in India, focusing on the energy value chain, water, waste, and transport sectors aligned with India's climate and sustainable development goals. It seeks USD 132.5 million in equity and USD 4.5 million in technical assistance grants from the Green Climate Fund, structured in two components: 1. Component I: Equity investment in the Green Growth Equity Fund (GGEF), an alternative investment fund mobilizing public and private sector capital for long-term equity investments in India's green infrastructure projects. GCF provides up to USD 132.5

	(India) EverSource Capital Private Limited - The Offshore Fund Green Growth Feeder Fund Pte. Ltd. ("GGFF") -Investment Manager of the Offshore Fund (Singapore) Everstone Capital Asia Pte. Ltd. ("ECA")	million to catalyze additional finance from institutional investors. 2. Component II: Technical Assistance (TA) Grant funding to establish a USD 4.5 million TA Facility at GGEF to address capacity, knowledge, and policy gaps hindering green infrastructure projects in India. The program complements existing initiatives in India while providing technical assistance to create an enabling environment for green infrastructure projects. It accelerates the adoption of low-carbon technologies and business models, contributes to GHG emission reductions (166 million tons of CO2 equivalent), and increases access to alternative water resources (5,700 million m3) through wastewater treatment and desalination plants. Additionally, the program promotes economic growth, job creation, environmental sustainability, and social development. It adheres to strong corporate governance standards and a participatory approach to infrastructure planning while addressing societal needs by enhancing access to affordable infrastructure and income generation. Overall, the program aligns with India's climate objectives, NDCs, and policy incentives, making it a comprehensive and impactful initiative. **Outcomes:** - Increased use of low-carbon transport - Lower energy intensity of buildings, cities, industries and appliances - Increased number of small, medium and large low-emission power suppliers
FP099 **Climate Investor One**	**Accredited Entity:** Nederlandse Financierings-Maatschappij voor Ontwikkelingslanden (FMO) **Executing Entities:** - Coöperatief Climate Fund Managers U.A. -Stichting Development Fund	Climate Investor One (CIO) is a blended finance facility. The first component of this programme is a development fund, which provides loans in the early stage of a project life cycle. The second component, a construction equity fund, will meet up to 75 percent of total construction costs in tandem with the project sponsor. Compared with conventional project financing, CIO removes the need for complex multi-party financing structures, with the potential to thereby reduce the time and cost associated with delivering renewable energy projects. **Outcomes:** - Increased number of small, medium and large low-emission power suppliers

	-Coöperatief Construction Equity Fund U.A. - Nederlandse Financierings - Maatschappij voor Ontwikkelingslanden N.V.(FMO)	
FP084 **Enhancing climate resilience of India's coastal communities**	**Accredited Entity:** UNDP **Executing Entity:** Ministry of Environment, Forest and Climate Change, Government of India **Co-Finance:** Public sector co-finance committed for the project	This project will strengthen the climate resilience of coastal communities by protecting and restoring India's natural ecosystems such as mangroves and seagrass, which are essential for buffering against storm surges. The project will also support climate-adaptive livelihoods and value chains to increase the climate resilience of these coastal communities. The project will be implemented in 24 target ecosystems in 12 coastal districts across the states of Andhra Pradesh, Maharashtra, and Odisha. The project's ecosystem restoration benefits have an estimated lifespan of 30 years. **Outcomes:** - Strengthened government institutional and regulatory systems for climate responsive development planning. - Strengthened adaptive capacity and reduced exposure to climate risks. - Enhanced resilience of coastal and marine ecosystems and their services - Climate adaptive livelihoods for enhanced resilience of vulnerable coastal communities - Strengthened governance and institutional framework for climate-resilient management of coastal areas
FP081 **Line of Credit for Solar rooftop segment for commercial, industrial and residential housing sectors**	**Accredited Entity:** NABARD: National Bank for Agriculture and Rural Development **Executing Entity:** Tata Cleantech Capital Limited **Co-finance:**	Enabling access to long-term, affordable finance for solar rooftop installation projects in commercial, industrial and residential housing sectors in India, including vulnerable communities. The programme will enable access to long-term and affordable financing for the construction of 250 MW of rooftop solar capacity in India and thereby reduce emissions by 5.2 million tonnes of CO_2 equivalent over 20 years. This pioneering private sector-driven initiative will unlock private sector investment in the rooftop solar market and pave the way toward a sustainable bankable model in India and beyond. **Outcomes:**

	Private Sector Banks	- Increased number of small, medium and large low-emission power suppliers.
FP045 **Ground Water Recharge and Solar Micro Irrigation to Ensure Food Security and Enhance Resilience in Vulnerable Tribal Areas of Odisha**	**Accredited Entity:** NABARD: National Bank for Agriculture and Rural Development **Executing Entity:** Groundwater Division of Department of Water Resources, Govt. of Odisha **Co-finance:** Government of Odisha	Enhancing the resilience of vulnerable communities in Odisha through groundwater recharge and solar micro irrigation. The ground water recharge measures will improve water security and quality for around 5.2 million beneficiaries in vulnerable communities through the installation of groundwater recharge shafts in 10,000 tanks. Tanks and ponds in the region provide effective rainwater collection but are inefficient at recharging groundwater due to low permeable soil. Ground water recharge shafts can be transformative by demonstrating their ability to recharge the underlying aquifier system, developing long-term groundwater reserves. At the same time, resilient crop planning through irrigation will improve food security in the region, whilst the use of solar pumps for irrigation will increase energy access and contribute to the state's climate-resilient, low emission crop planning. **Outcomes:** - Strengthened institutional and regulatory systems for climate-responsive planning and development

Appendix 4 – Indicative project pipeline: Risk Sharing Facility for CBG lending

This portion has been redacted in accordance with the GCF Information Disclosure Policy, as the portion is confidential under the disclosure policy of the Accredited Entity