Indian Public Policy Review 2025, 6(4): 35-85
https://doi.org/10.55763/ippr.2025.06.04.002

IPPR

India's Climate Finance Requirements: An Assessment

Janak Raj[*]

Rakesh Mohan[#1]

Abstract

This study assesses India's climate finance requirement from 2022-2030 to decarbonise its four major carbon-emitting sectors—cement, steel, power, and road transport. Climate finance or additional capital expenditure (capex) for transitioning to a low-carbon economy, i.e., over and above the capex already planned in the business-as-usual (BAU) scenario, has been estimated at US$467 billion for 2022-2030 or 1.3 per cent of India's gross domestic product (GDP) annually. This comprises US$251 billion for the steel sector, followed by US$141 billion for cement, US$57 billion for power and US$18 billion for road transport. The estimated investment in the four sectors will reduce the use of 291 million tonnes of coal and 72 billion litres of petrol and diesel, mitigating 6.9 billion tonnes of CO2 emissions (excluding road transport). The study also evaluated the macroeconomic consistency of India's estimated climate finance requirement. Overall, capital and financial flows net of the projected current account deficit (CAD) for India are estimated at US$530 billion during 2023–2030 as against the projected expansion of US$474 billion in monetary base. Thus, India would need to skilfully manage both (i) capital flows in the BAU; and (ii) climate finance from external sources. India may have to strategically widen its CAD, subject to a maximum of 2.5 per cent of GDP.

Keywords: Climate Finance, Low carbon economy, Current Account Deficit, decarbonisation

Publication Date: 01 October 2025

[*] Janak Raj is a Senior Fellow at the Centre for Social and Economic Progress (CSEP), New Delhi
[#] Rakesh Mohan is President Emeritus and Distinguished Fellow, Centre for Social and Economic Progress (CSEP), New Delhi

Abbreviations

ACE	Additional Capital Expenditure
BAU	Business-as-usual
BF-BOF	Blast Furnace-Basic Oxygen Furnace
BOS	Basic Oxygen Steelmaking
CAD	Current Account Deficit
CAGR	Compound Annual Growth Rate
Capex	Capital Expenditure
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation, and Storage
CEA	Central Electricity Authority
COP	Conference of the Parties
CRF	Capital Recovery Factor
CSE	Centre for Science and Environment
DAC	Direct Air Capture
DRI	Direct Reduced Iron
e2w	Electric two-wheeler
EAF	Electric Arc Furnace
EMDEs	Emerging Markets and Developing Economies
EVs	Electric Vehicles
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GOI	Government of India
ICEVs	Internal Combustion Engine Vehicles
IEA	International Energy Agency
IIHS	Indian Institute of Human Settlements
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hour
MoEFCC	Ministry of Environment, Forest, and Climate Change
MDBs	Multilateral Development Banks
MSS	Market Stabilisation Scheme
NAPCC	National Action Plan on Climate Change
NDAs	Net Domestic Assets

NDC	Nationally Determined Contribution
NFAs	Net Foreign Assets
OPC	Ordinary Portland Cement
OPEX	Operational Expenditure
PLF	Plant Load Factor
PPC	Pozzolana Portland Cement
PSC	Portland Slag Cement
PSE	Public Sector Enterprise
RBI	Reserve Bank of India
RD	Revenue Deficit
R&D	Research and Development
RE	Renewable Energy
RM	Reserve Money
SDGs	Sustainable Development Goals
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

Global CO_2 emissions have been on a relentless rise, driven by industrialisation, deforestation and the burning of fossil fuels. CO_2 emissions reached a record high of 37 billion tonnes in 2023, up from 33 billion tonnes in 2010 and 26 billion tonnes in 2000 (Global Carbon Budget, 2023). The increase in global temperatures, approximately 1.1 degrees Celsius since pre-industrial times (NASA, 2022), has led to frequent and severe weather events like hurricanes, droughts and floods, devastating communities, and ecosystems. Melting polar ice caps and glaciers contribute to rising sea levels, threatening coastal cities, and habitats, with an eight-inch rise since 1880 (NASA, 2022). Ocean acidification from increased CO_2 absorption disrupts marine life and food chains, severely affecting coral reefs, which support about 25 per cent of marine species (US-EPA, 2024). These changes threaten global food security, health, and economic stability.

Changing weather patterns will lead to potential food shortages and higher prices, with a projected 15.9 per cent global decrease in agricultural productivity by the 2080s (Fischer *et al.*, 2005; Pickson & Boateng, 2021). In rural areas, adverse climate effects like higher temperatures, salinity intrusion, and irregular rainy seasons reduce agricultural and livestock output, increase herd mortality, and threaten food security (Chowdhury *et al.,* 2022; Meyfroidt, 2018). Health issues, including heat-related illnesses and vector-borne diseases, pose further threats. Economically, climate-related disasters could cost up to US$38 trillion annually by 2050 (Potsdam Institute for Climate Impact Research, 2024). Despite these rather disturbing data, meaningful action is still missing as policymakers the world over prioritise short-term economic gains over long-term sustainability, exacerbating the climate crisis.

India is poised to be one of the most affected nations by climate change due to a combination of geographic, economic, and social factors. The country is particularly exposed to the physical risk of climate change. The urgency of India’s transition in the context of climate change is highlighted by the Global Climate Risk Index 2021, which ranked India as the seventh most affected country in terms of exposure and vulnerability to climate risks (Germanwatch, 2021). Similarly, another report found that India is the most vulnerable country to climate change, followed by Pakistan, the Philippines and Bangladesh (HSBC Report, 2018). The risk of climate change looms large, with a potential estimated per capita gross domestic product (GDP) loss due to climate change in India of around (-) 2.0 per cent, with other impacts on temperature, precipitation, and urbanisation. By 2047, the impact of climate change could be more negative, ranging from a 3 per cent to 9 per cent reduction in GDP, depending on risk mitigation efforts (RBI, 2023).

Currently, India’s share in global carbon emissions is at 7.6 per cent, with annual emissions of 2.8 billion tonnes in 2022. This is projected to have increased further by 8.2 per cent in 2023 (Global Carbon Budget, 2023). However, the Climate Transparency Report (2022) indicates that despite these increases, India's per capita emissions remain lower than the global average. This is partly due to the country's relatively lower energy consumption per person compared to more developed nations.

Despite its contribution to cumulative global greenhouse gas (GHG) emissions being significantly lower than that of major developed countries, India has been active in climate action. It has been actively participating in various climate action committees, including the United Nations Conference of the Parties (COP) and the Nationally Determined Contributions (NDCs).

India's commitment to addressing climate issues is demonstrated through its consistent efforts not only to set ambitious targets but also to meet them, reflecting its commitment to sustainable development and environmental stewardship. India's NDC targets reflect its comprehensive and forward-thinking approach to climate action. These targets include (i) achieving net-zero CO_2 emissions by 2070; (ii) reducing the carbon intensity of India's GDP by 45 per cent by 2030; (iii) increasing non-fossil energy capacity to 500 gigawatts by 2030; and (iv) fulfilling 50 per cent of energy needs from renewable sources by 2030. It is significant that the country has made rapid strides in reducing its carbon footprint. The emission intensity relative to GDP was reduced by 36 per cent between 2005 and 2020, against the initial target of 33-35 per cent by 2030. Second, it also achieved 46.3 per cent of its installed electric capacity through non-fossil fuel sources. Both these targets were achieved well ahead of time in 2023, as against the deadline set for 2030.

To address climate risks while maintaining high growth rates, it is becoming increasingly important for India to adopt effective climate adaptation and mitigation measures. The existing estimates of climate finance requirements for India range from US$160 billion to US$288 billion annually (Climate Policy Initiative, 2022; Singh & Sidhu, 2021; IEA, 2022; MoEFCC, 2015; IIHS, 2023; McCollum *et al.,* 2018). However, the underlying methodologies of these climate finance requirements raise some concerns. First, the wide range between the lowest (US$160 billion) and highest (US$288 billion) estimates indicates significant uncertainty and differences in the scope of financial estimates (like mitigation versus adaptation) and diverse economic and climate models. Second, the lack of detailed explanations of underlying methodologies hampers the critical scrutiny of the estimates made. Third, these estimates are based on top-down approaches and financial models and hence do not capture the granular and sectoral impacts of climate change, leading to overgeneralisation and the overlooking of sectoral needs. Furthermore, the accuracy of these estimates is compromised by the frequent use of outdated, limited or vague data on climate impacts and costs.

In view of the above-referred limitations of various climate finance estimates available for India, the need was felt to assess the climate finance requirements of India following a bottom-up approach. Of the various sources of carbon emissions, four major carbon-emitting sectors in India are power, steel, cement, and road transport. They contributed more than 50 per cent of carbon emissions in the country in 2023. Therefore, in this study, we assess the climate finance requirements of these four sectors. While most studies cover the energy sector for assessing climate finance estimation, studies covering the steel, cement and road transport sectors are few and far between. The period covered is 2022–2030,[2] as it becomes extremely challenging to assess climate finance requirements for the distant future due to several uncertainties and imponderables, which are difficult to gauge. By focusing on the primary sources of CO_2 emissions, the study seeks to provide a more accurate and granular understanding of the financial needs of the country for effective decarbonisation.

The climate finance estimates in this paper reflect the additional capital expenditure (ACE) required solely for mitigation or moving to a low-carbon economy, *i.e.,* over and above the investment needed in the business-as-usual (BAU) scenario in these sectors. In the power sector, the study focuses on the additional capital expenditure (capex) required for expanding renewable energy capacity and storage to support a higher share of renewables. In the road transport sector, the study evaluates the funding needed for the electrification of the road transport fleet (two-wheelers, three-wheelers, passenger cars and taxis, trucks/goods vehicles and buses) and for developing the charging infrastructure. In the steel and cement sectors, the study estimates the capital expenditure required to adopt cleaner technologies such as carbon capture and storage (CCS) and through other pathways such as energy efficiency, alternative fuels and the use of renewables. In addition, for the cement sector, the study also estimates the cost associated with transitioning to low-carbon production processes and materials (clinker substitution).

The two different methodologies used for the power and road transport sectors on the one hand, and for the steel and cement sectors on the other, will have different impacts on the mitigation of CO_2. Climate finance estimates for power and road transport are based on the progressive transition from fossil fuel to non-fossil fuel-based sources of energy. This implies that the estimates made for these two sectors assume that CO_2 emissions from these two sectors are only partly mitigated. The mitigation of CO_2 emissions in these sectors will take place gradually, as the share of fossil fuel usage declines and is replaced by renewable energy in the power sector, and by electric vehicles (EVs) in the road transport sector. However, climate finance estimates for the steel and cement sectors account for full mitigation of CO_2 in existing capacity up to 2022, and of the incremental CO_2 that will be emitted from the new capacity to be added till 2030.

Climate finance requirements will need to be met from both external and domestic sources. An Independent High-Level Expert Group on Climate Finance estimated, in 2022, the external finance requirements for emerging markets and developing economies (EMDEs), other than China, at US$1 trillion per year up to 2030 (Bhattacharya *et al.*, 2022). However, the actual experience of climate finance from external sources to emerging economies aggregated to less than US$300 billion (from developed economies, the International Monetary Fund - IMF and multilateral development banks - MDBs in 2023. Of this, India received less than US$8 billion of climate finance from official external sources (Raj *et al.,* 2024). Nevertheless, the need for climate finance from external sources for developing economies, including India, can hardly be overemphasised, with developing countries emphasising the need for larger funds from external sources. India, in a submission to the United Nations Framework Convention on Climate Change (UNFCCC), has called for developed countries to provide at least US$1 trillion a year in climate finance to developing countries from 2025 onwards (UNFCCC, 2024).

A country's ability to absorb external capital flows is limited by the extent of its current account deficit (CAD), supplemented by the accretion to its forex reserves consistent with the expansion of its monetary base or reserve money or high-powered money. India normally runs a CAD, but capital and financial flows have generally exceeded its CAD. This has enabled appropriate accretion to its foreign exchange reserves and a corresponding expansion of net foreign assets in the balance sheet of the Reserve Bank of India (RBI). As the ability to manage capital and financial flows more than the CAD is influenced by the requirement of expansion in the monetary base, this study also examines the extent to which India can manage climate finance flows from external sources consistent with the expansion in monetary base.

Thus, this study examines two issues. First, it evaluates the climate finance needs of India's four major carbon-emitting sectors: power, road transport, steel, and cement. Second, it examines the macroeconomic consistency of the estimated climate finance.

Several key findings emerge from the study. First, the total climate finance requirements for India in the four key sectors are estimated at US$467 billion (at current prices) for 2022–2030,[3] which works out to US$54 billion or 1.3 per cent of its GDP, annually.

About US$251 billion of the estimated climate finance is required for the steel sector and US$141 billion for the cement sector. Both the steel and cement are hard-to-abate sectors and require largely the use of CCS technology to decarbonise them, which is expensive to deploy but is the only feasible option at this juncture. India is estimated to require US$47 billion for switching over from fossil-fuel based sources of power to non-fossil based, over and above the investment planned for the power sector in the BAU scenario for the period from 2024 to 2030. In addition, renewables also require storage cost estimated at US$10 billion, because of which the total additional capex for the power sector works out to US$57 billion. The country will require an additional capex of US$10 billion for the electrification of the road transport fleet. In addition, capex for developing the charging infrastructure for EVs[4] is estimated at US$8 billion, thus requiring an overall climate finance of US$18 billion for road transport.

The estimated climate finance for all four sectors would result in reduction in the use of 291 million tonnes of coal and 72 billion litres of petrol and diesel, mitigating 6.9 billion tonnes of CO_2 emissions (excluding road transport, for which CO_2 mitigation could not be worked out as the relevant data were not readily available).

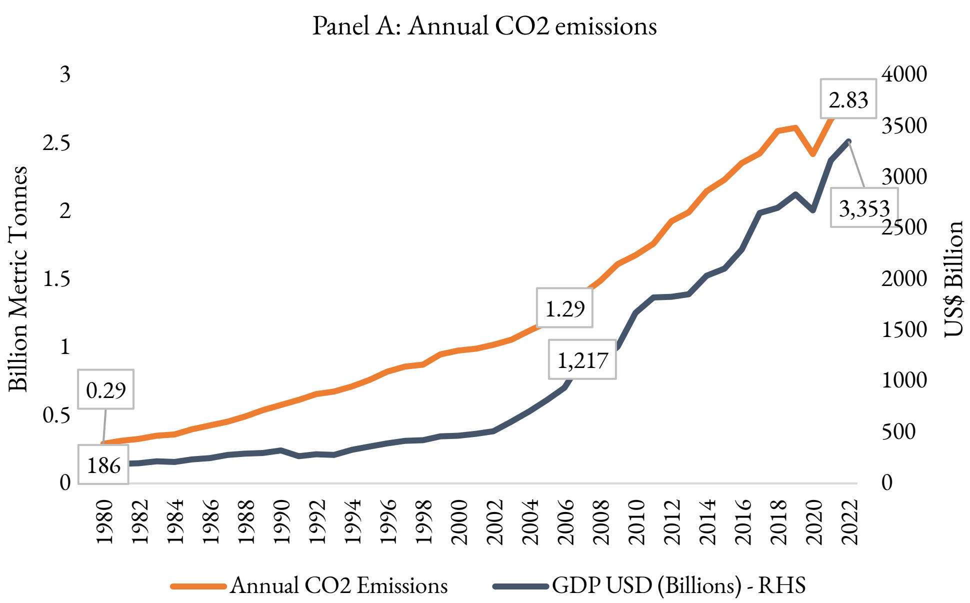
The CAD of India is projected to average 1.9 per cent of GDP (in the range of 1.0–2.4 per cent of GDP) during 2023–2030 in the BAU scenario. Capital and financial flows into the economy are projected in the range of 2.4–3.8 per cent of its GDP for the same period. Net of the CAD, capital and financial flows for India are estimated at US$530 billion during 2023–2030, *i.e.,* 1.4 per cent of GDP on an annual average basis. However, consistent with the projected expansion in the monetary base, India will be able to manage capital and financial flows net of CAD only up to US$474 billion[5] during the same period. Thus, large capital and financial flows in the BAU scenario and climate finance flows from external sources would need to be managed skilfully. For absorbing climate finance flows from external sources, India may have to judiciously widen its current account deficit (CAD), subject to a maximum of 2.5 per cent of GDP, consistent with the availability of climate finance from external sources. The remaining gap may have to be financed from domestic sources by increasing the saving rate.

The structure of the study is as follows: Section 2 examines India's share in global carbon emissions and the major sources of historical and current levels of carbon emissions in India. Section 3 offers a thorough and critical review of existing studies that have estimated climate finance requirements for India and details the limitations of these estimates. Section 4 estimates the climate finance needed in the cement, steel, power and road transport sectors in India from 2022–2030. Section 5 evaluates the macroeconomic consistency of the estimated climate finance requirements. The final section sums up the key findings, spells out policy implications and lists the major limitations of this study.

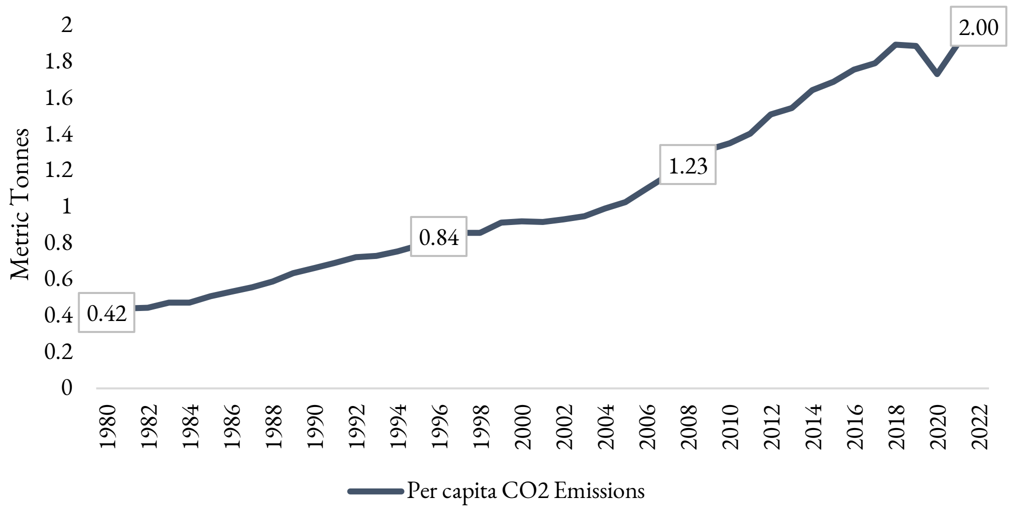
2. India's Carbon Footprint and Economic Risks

According to the Global Carbon Budget Report (2023), while carbon emissions were set to decline by 3 per cent in the US and 7.4 per cent in the European Union, they were projected to increase in India significantly by 8.2 per cent in 2023 on account of its rapid growth and industrialisation. India's carbon emissions have exhibited an upward trend, driven by the country's rapid economic growth and increasing energy demands (Figure 1). The last decade witnessed a substantial expansion in industrial activity and urbanisation, which, while boosting economic output, also intensified carbon emissions. This spike was exacerbated by a weak monsoon, which decreased hydropower production and increased reliance on fossil fuels for electricity.

Figure 1: Annual CO_2 Emissions and Per Capita CO_2 Emissions - India



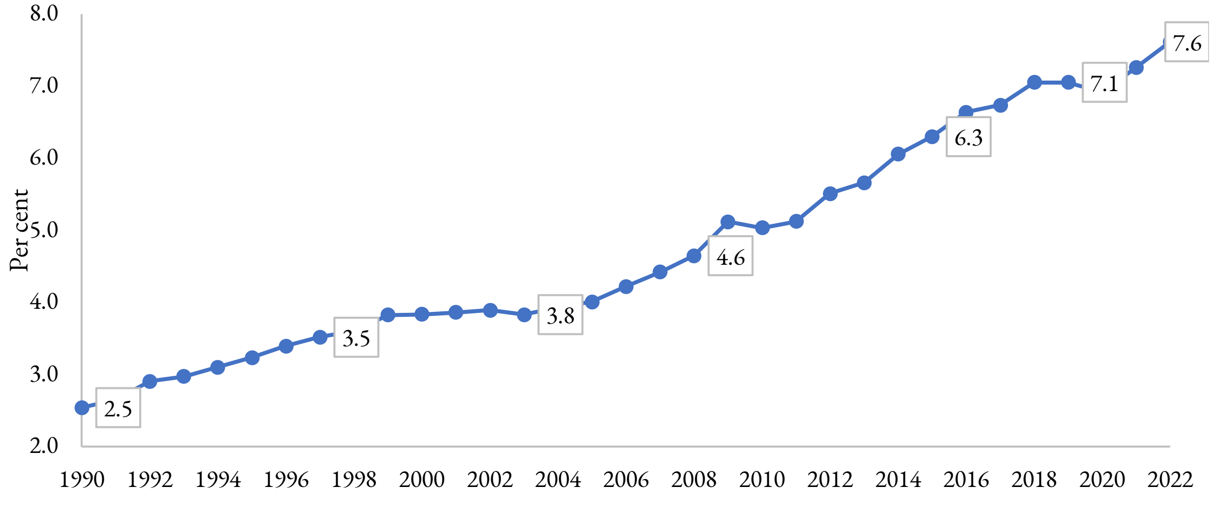
Panel B: Per Capita CO_2 Emissions



Source: Global Carbon Project Database, 2023.

India's share in global carbon emissions rose from 2.5 per cent in 1990 to about 7.6 per cent in 2022, and it was estimated to have risen further to 8.2 per cent in 2023 (Figure 2).

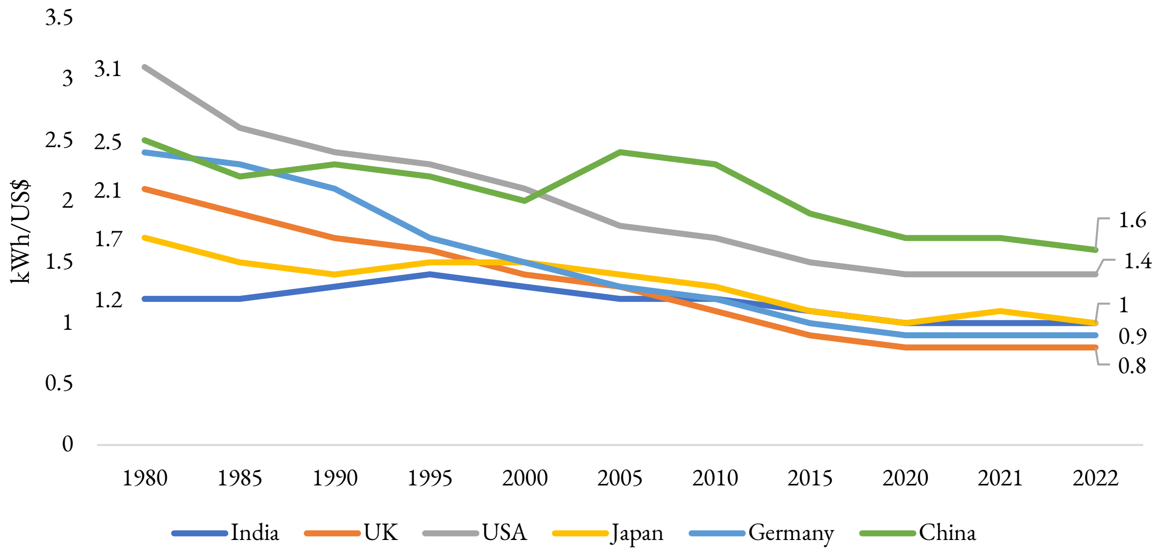
Figure 2: India's Share in Global Carbon Emissions



Source: Global Carbon Project Database, 2023.

The energy intensity of GDP helps us understand how efficiently countries are using energy to generate economic output. The energy intensity of India's GDP declined between 1980 and 2022, indicating improved energy efficiency in generating economic output (Figure 3). However, compared to the UK, Japan, and Germany, India's energy intensity is still higher, suggesting that despite the progress made, there is still significant room to reduce energy intensity. Notably, China, with one of the highest initial energy intensities, has shown a significant reduction, though its energy intensity remains the highest among major economies.

Figure 3: Energy Intensity of GDP

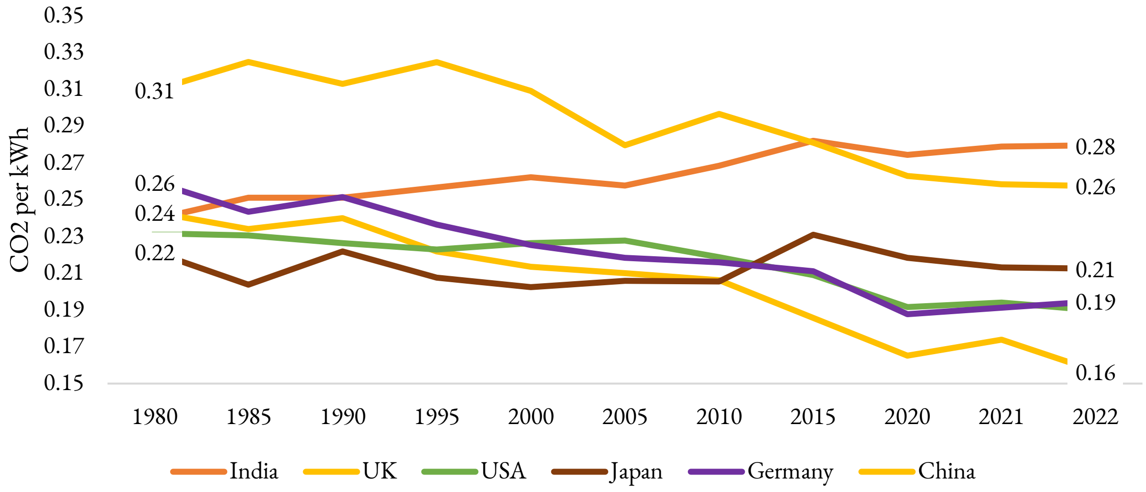


Note: Energy intensity of GDP measures the total amount of energy required to produce one unit of GDP. This data has been adjusted for inflation and differences in the cost of living between countries and is expressed in international dollars at 2011 prices.
Source: U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2023); Bolt and van Zanden - Maddison Project Database 2023 (2024).

Similarly, India's carbon intensity of energy production, *i.e.,* the amount of CO_2 emitted per unit of energy produced, expressed in kilograms of CO_2 per kilowatt-hour, has remained relatively high over the years and has been on the rise, indicating a heavy reliance on fossil fuels, especially coal, for energy production (Figure 4). Despite efforts to diversify its energy mix with renewable sources like solar and wind, the decline in carbon intensity has been gradual. This suggests that while renewable energy capacity is increasing, overall energy production is still heavily dominated by fossil fuels, which has slowed the reduction in carbon intensity. India's progress in lowering carbon intensity is slower relative to developed countries like the UK, the US, Germany, and Japan. These countries have made significant advancements in clean energy technologies, resulting in a more substantial reduction in carbon intensity. China, which had a high carbon intensity similar to India, has shown a more pronounced decrease due to aggressive investments in renewable energy and cleaner technologies (Figure 4).

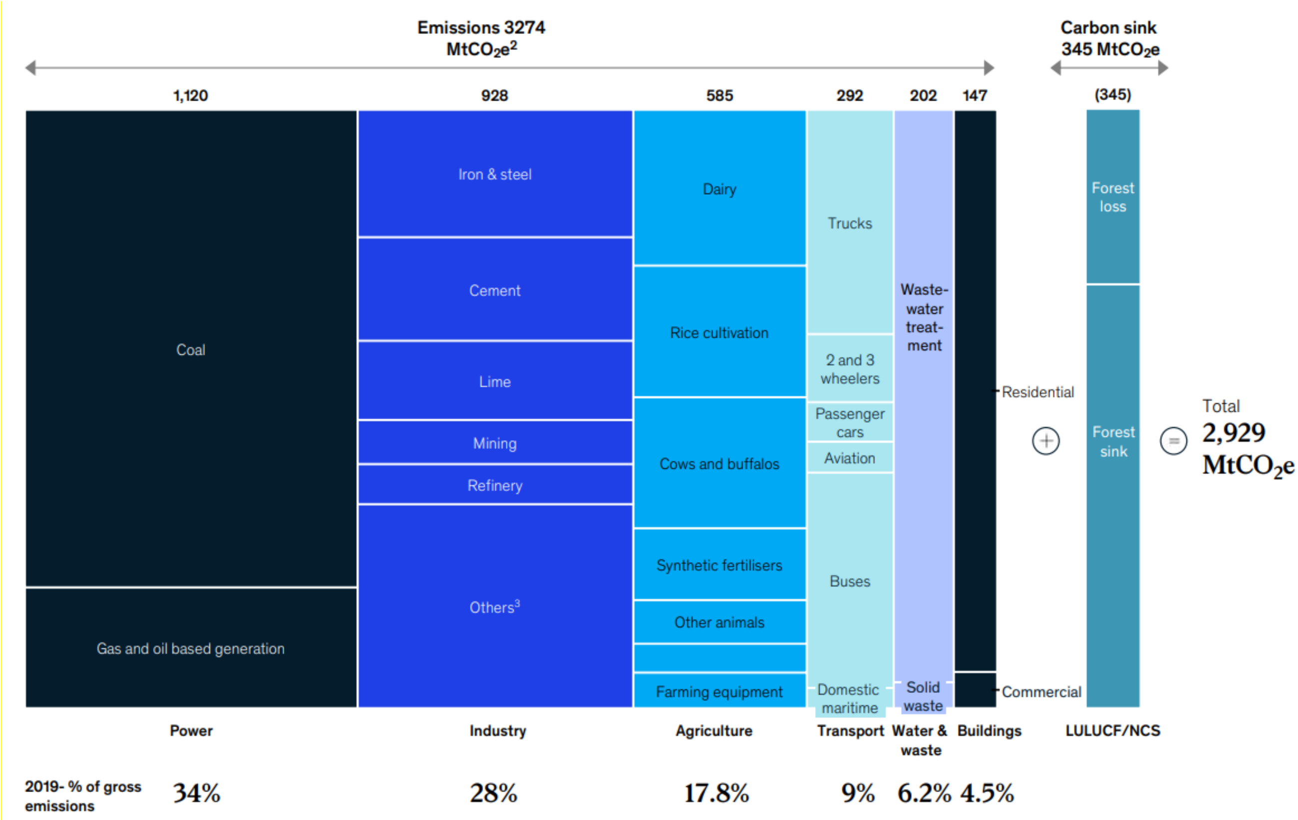
India's carbon emissions in 2019 were 3,274 MT of CO_2 equivalent ($MtCO_2e$), with net emissions of 2,929 $MtCO_2e$ after accounting for carbon sinks (Figure 5). The power sector was the largest contributor to emissions, responsible for 34 per cent of gross emissions, predominantly from coal-, gas- and oil-based generation. This was followed by the industrial sector, contributing 28 per cent of emissions, with major contributors being iron and steel, cement, lime, mining, and oil refineries. The share of agriculture in emissions was 17.8 per cent, driven by activities such as dairy farming, rice cultivation, emissions from cows and buffaloes, synthetic fertilisers and other livestock. The transport sector contributed 9 per cent of emissions, with trucks, passenger cars and buses, and civil aviation being the primary sources.

Figure 4: Carbon Intensity of Energy Production



Source: Global Carbon Budget (2023); U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2023).

Figure 5: Sources of Carbon Emissions - India



Source: Decarbonising India: Charting a Pathway for Sustainable Growth, McKinsey, 2022.

India remains one of the most vulnerable countries to climate change given its long coastline and a large, monsoon-dependent agrarian economy. According to India's Centre for Science and Environment (CSE), the country experienced extreme weather events on 314 of the 365 days of 2022, which claimed about 3,000 lives, affected 2 million hectares of crop area and 400,000 houses, and killed over 70,000 animals (RBI, 2023). By 2030, India could account for 34 million of the projected 80 million global job losses from heat stress-associated productivity decline (World Bank, 2022). Loss of labour from rising heat and humidity could put up to 4.5 per cent of India's GDP – about US$150–250 billion – at risk by the end of this decade (McKinsey & Company, 2020). The estimated per capita GDP loss due to climate change in India is around (-)2.6 per cent in 2030, with other impacts on temperature, precipitation and urbanisation. By 2047, the impact of climate change could be more negative, ranging from a 3 per cent to 9 per cent reduction in GDP, depending on risk mitigation efforts (RBI, 2023). Climate-related risk can also lead to inflation volatility. In 2019 alone, India lost nearly US$69 billion due to climate-related events, which is in sharp contrast to the US$79.5 billion lost over 1998–2017. The cost of climate change in India is estimated at Rs 85.6 trillion at 2011–2012 prices, or about US$2 trillion by the year 2030 (RBI, 2023).

Agriculture, a critical sector for India's gross value-added and livelihoods, shows high sensitivity to climatic factors, with significant non-linear impacts (Gupta et al., 2022). Climate change has impacted rising temperatures and changing patterns of monsoon rainfall in India. It is disrupting crop cycles and yields, which can hit the rural economy and push up inflation in urban areas as well. The impact of climate change on different states has also been divergent. The adverse effects of climate change are heavily concentrated in already poorer states in eastern India that are highly involved in coal mining, especially Jharkhand, West Bengal, Odisha, and Bihar (RBI, 2023).

Considering the devastating impact of climate change on the economy, India has consistently set ambitious targets under its NDCs and met some of them way before the deadlines set (Box 1).

Box 1: India's Nationally Determined Contribution Under the Paris Agreement

India submitted its intended Nationally Determined Contribution to the UNFCCC on October 2, 2015. In August 2022, India updated its first NDC for the period up to 2030.

The key commitments made by India as part of NDC are detailed below:

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 Emissions Intensity of its GDP by 45 per cent by 2030 from the 2005 level.
4. To achieve about 50 per cent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030, with the help of 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 CO2 equivalent through additional forest and tree cover by 2030.
6. To better adapt to climate change by enhancing investments in development programs in sectors vulnerable to climate change, particularly agriculture, water resources, Himalayan region, coastal regions, health, and disaster management.
7. To mobilise domestic and new & additional funds from developed countries to implement the above mitigation and adaptation actions in view of 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.

Source: Government of India 2022.

3. Climate Finance Estimates for India

India's climate finance estimates for achieving its climate goals have evolved over the years with the addition of ambitious targets every year. Before the NDC commitments in 2015, the Government of India (2012) estimated that achieving the National Action Plan on Climate Change (NAPCC) objectives would cost around US$240 billion (assuming US$1 = Rs 60) from 2012 to 2020, cumulatively. In its NDC, India pledged to reduce the emissions intensity of CO_2 of its GDP by 33 per cent from 2005 levels by 2030 and to achieve 40 per cent of its cumulative installed power capacity from clean energy sources. To meet these targets, US$2.5 trillion (in 2014–2015 prices) was estimated to be required from 2016 to 2030 (Government of India, 2015), translating to approximately US$167 billion annually, which was nearly 8 per cent of India's GDP in 2014–2015. NITI Aayog[6] (2014) projected that a moderately low-carbon strategy would necessitate US$834 billion (at 2011 prices) between 2010 and 2030, considering the costs of technological transitions, R&D, intellectual property rights, and capacity building. India must increase its annual climate investments from 2018 by a factor of nine to achieve its NDC targets (Jena & Purkayastha, 2020; Sinha *et al.,* 2020). In line with this, Vishwanathan and Garg (2020) estimated that an investment of US$2.37 trillion (in 2014–2015 prices) would be required from 2015 to 2030.

Achieving deep decarbonisation necessitates: (i) the expansion of energy storage facilities; (ii) the phasing out of inefficient power plants; (iii) the transition to cleaner fuels; (iv) the implementation of energy-efficient technologies; and (v) the installation of CCS technologies. Transforming the energy sector on this scale has been estimated to require investments ranging from US$6 to US$8 trillion in current prices between 2015 and 2030 cumulatively (Vishwanathan & Garg, 2020). McCollum *et al.* (2018) found that the total capital required to transform the energy system in line with a 1.5°C or 2°C scenario by 2030 for India is significantly higher than the investment needs for most other UN 2030 Sustainable Development Goals (SDGs). Such SDGs include food security, education, and sanitation. According to this study, while energy investments amount to several trillion dollars for India, the latter require only a few hundred billion dollars. Similarly, Zhou *et al.* (2020) estimated that the investment needs for SDG 7 (to ensure that everyone has access to affordable, reliable, sustainable, and modern energy) are much greater than those for other SDGs.

Recent reports provide a range of estimates for India's climate finance needs: the Climate Policy Initiative (2022) and its Sub-Committee Report suggest US$170 billion annually till 2030 to meet India's NDC commitments. A study by Singh and Sindhu (2021) estimated US$202 billion annually to achieve net-zero carbon emissions by 2070. The International Energy Agency (IEA, 2022) projects an average annual requirement of US$160 billion to reach net-zero emissions by 2070. The Ministry of Environment, Forest, and Climate Change (MoEFCC, 2015) and a 2023 report by the Indian Institute of Human Settlements (IIHS) suggest US$167 billion annually from 2016 to 2030 to meet targets set under the NDC. McCollum *et al.* (2018) estimate US$288 billion annually for staying below 1.5°C from 2016 to 2050 (Table 1). In the context of sectoral requirements, a recent assessment indicates that the existing steel plants in India alone would require a US$283 billion investment to become green (Verma *et al.*, 2024).

Table 1: Climate Finance - Various Estimates for India

Source	Target	Estimate
Climate Policy Initiative 2022 and its Sub-Committee Report	Till 2030 for NDC	US$170 billion per year (2016–2030).
Singh and Sidhu, Council on Energy, Environment, and Water—Centre for Energy Finance, 2021	Net-zero carbon emission by 2070	US$202 billion per year.
International Energy Agency, 2022	To reach net-zero emissions by 2070	US$160 billion per year on average between 2022 and 2030.
Ministry of Environment, Forest and Climate Change of India (MoEFCC) (2015); Climate Finance in India (2023) Report by Indian Institute for Human Settlements (IIHS).	NDC targets	US$167 billion annually from 2016–2030
McCollum *et al.,* 2018	Below 1.5°C from 2016–2050	US$288 billion per year between 2016 and 2050.

Source: Compiled by authors.

3.1 Climate Finance Estimates for India–Some Issues

Various climate finance estimates available for India are not strictly comparable for a variety of reasons, and there is a need to be cognisant of several limitations of these estimates.

First, the range between the lowest estimate of US$160 billion and the highest estimate of US$288 billion is quite large. This arises from differences in the scope of actions covered such as: (i) whether the focus of coverage is on mitigation efforts or adaptation strategies; and (ii) whether the estimates are aligned with achieving the Paris Agreement objectives by 2030, fulfilling NDCs or attaining global net-zero emissions by 2050 and/or 2070. Additionally, the wide range is influenced by the use of diverse economic and climate models, which incorporate various assumptions and scenarios, further contributing to the variation in estimated costs. This makes them highly sensitive to a range of assumptions about the rates of climate change, technology costs, policy implementations and economic growth trajectories. Even minor adjustments in these assumptions can significantly increase the uncertainty of the projections and substantially influence the overall climate finance estimates. This inherent sensitivity underscores the challenge of producing reliable and consistent climate finance estimates, highlighting the need for more robust, flexible, and inclusive approaches to better capture the complex and dynamic nature of climate change impacts.

Second, the existing estimates rely predominantly on top-down approaches and financial models. These methods often fail to capture the detailed, sectoral impacts of climate change, resulting in overgeneralisation and the neglect of specific sectoral needs. This overgeneralisation means that the unique challenges and requirements of various sectors are not adequately considered, leading to a "one-size-fits-all" approach that overlooks the diversity of climate change effects across sectors. Additionally, some estimates focus on decarbonising specific sectors such as energy or land use systems, while others provide multi-sectoral assessments that even include adaptation measures in some cases. Unlike global estimates, most of the studies for India have considered water supply and sanitation, flood protection, adaptation and resilience, and loss and damage.

Third, the baselines used to arrive at these estimates are often inconsistent or lack transparency. Different studies employ varying baselines or BAU scenarios to project additional capital expenditure requirements, but many of these baselines are either not well-defined or are inadequately explained. This inconsistency in baseline selection can lead to significant variations in the estimated financial needs, making it challenging to compare and aggregate findings across different studies. Moreover, the lack of detailed methodological explanations hampers close scrutiny of these estimates.

Lastly, there is often ambiguity in some studies regarding whether the financial estimates pertain solely to climate-related expenditures or if they also encompass capital expenditures for broader developmental needs in the BAU scenario. This lack of clarity can obscure the true extent of the financial requirements for addressing climate change, as it becomes difficult to discern how much of the estimated funding is dedicated to direct climate actions *vis-à-vis* general development goals.

Recognising the shortcomings in the current estimates, it is useful to evaluate India's climate finance requirements through a granular bottom-up approach. Accordingly, this study estimates the climate finance requirements of India for the four sectors (power, road transport, steel, and cement) by clearly outlining the methodology employed and the specific assumptions made.

By concentrating on these primary sources of CO_2 emissions, the study aims at offering a more precise and detailed understanding of the financial requirements necessary for effective decarbonisation. This approach ensures that the financial needs are not only accurately quantified but also aligned with the specific characteristics and challenges of each sector.

The climate finance estimates presented in this paper are focused exclusively on the additional financial resources required for mitigation efforts, *i.e.,* specifically those aimed at transitioning to a low-carbon economy. It is important to clarify that these estimates assume that the country will continue to invest in the BAU scenario. In other words, the analysis takes for granted the existing and expected investments in maintaining current economic operations and infrastructure. Therefore, the estimates provided represent only the incremental or additional investments needed over and above those BAU investments, specifically targeted at mitigating carbon emissions and fostering a low-carbon economy.

4. Key CO_2 Emitting Sectors - Climate Finance Needs

4.1 Power and Transport Sectors - Methodology for Estimating Capital Expenditure

The climate finance estimated in this study has been defined as additional capital expenditure (capex) required for moving to a low carbon economy, *i.e.,* over and above the capex already planned in the BAU. In the power sector, it essentially implies switching from fossil fuel-based sources of power to renewables (power sector) and from ICEVs to EVs (road transport sector) due to climate change. This, in turn, entails the difference between the capex required for these two sectors (considering the climate change) and the capex in the BAU scenario (*i.e.* without considering the impact of climate change). The capex planned (considering climate change) can be estimated based on the official projections of installed capacity (power sector) and vehicle sales[7] (road transport sector), data on which are readily available. However, the capex in the BAU scenario has been estimated based on the methodology adopted in Box 2.

Box 2: Methodology for Assessing the BAU scenario Installed Capacity (Power Sector) and Vehicle Sales (Road Transport)

For estimating the installed capacity in the power sector and vehicle sales in the BAU scenario, it was assumed that the additional total installed power capacity and the number of vehicles will not be affected by climate change. That is, the overall requirement of power and vehicles would not be impacted by climate change. The only effect of the climate change will be on the energy and vehicle mix, *i.e.*, a switchover from fossil-fuel based sources of energy to non-fossil-based sources of energy and from ICEVs to EVs. The challenge then was to assess a change in the mix in the BAU scenario, for which the following steps were followed:

a) Estimation of the compound annual growth rate (CAGR) of **total** installed capacity (fossil fuel based and non-fossil fuel based) and total sales of vehicles (ICEVs and EVs) for the last 10 years.
b) Estimation of the CAGR of **fossil fuel**-based installed capacity and **ICEV** sales for the last 10 years.
c) Estimation of the CAGR of installed capacity of all sources of power and all vehicle sales based on official projections between 2030 and the latest available data (2022/2023).
d) Normalisation of the CAGR of installed capacity of fossil fuel-based sources of energy/ICEVs sales of past 10 years with the projected growth up to 2030 to arrive at their BAU scenario CAGR as explained below:

$$CAGR_{BAU_{installed\ capacity\ of\ fossil\ fuels\ /ICEVs\ Sales}}$$

$$= CAGR_{installed\ capacity\ of\ fossil\ fuels\ /ICEVs\ sales}\ (2012\ to\ 2022) \times \frac{CAGR_{total\ installed\ capacity\ of\ power\ /vehices\ sales}\ (2022\ to\ 2030)}{CAGR_{total\ installed\ capacity\ of\ power\ /vehices\ sales}\ (2012\ to\ 2022)}$$

e) Estimation of installed capacity of fossil fuel-based sources of power/ICEVs sales in 2030 based on the normalised CAGR using the values obtained at step (d).
f) Fossil-fuel installed capacity/ICEVs sales arrived at for 2030 based at step (e) above was deducted from total projected installed capacity of sources of power/total vehicle sales for 2030 to arrive at installed capacity of non-fossil fuel-based power/EV sales for 2030 in the BAU scenario as illustrated below:

BAU installed capacity of non-fossil fuel-based sources/EV sales = Projected total installed capacity of sources of power/total vehicle sales for 2030—installed capacity of fossil-fuel based power/ICEV sales in the BAU scenario as arrived step (e).

The above methodology essentially boils down to estimating the growth of fossil-fuel based sources of power and ICEVs in the past 10 years adjusted for future growth. As expected, this methodology gives consistently higher CAGR for installed capacity of conventional sources of power/sales of ICEVs in the BAU scenario *vis-à-vis* those based on projections (relative to the initial year) and lower CAGR for installed capacity of non-conventional sources/sales of EVs.

Estimation of EV sales in the BAU scenario - An Illustration:

Vehicle Type	Number of Vehicle Sales - 2012	Number of vehicles Sold - 2022	Projected sales of vehicles - 2030	Past CAGR of sales vehicles (2012-2022)	CAGR based on Projected sales	Projections in the BAU scenario (2022-2030)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
ICEV	179	203	243	0.01	0.02	274
EV	0	12	125	-	-	94
Total	179	215	368	0.02	0.06	368

$$CAGR_{total\ vehicles}\ (2012\ to\ 2022) = 0.02$$

$$CAGR_{total\ vehicles}\ (2022\ to\ 2030) = 0.06$$

$$CAGR_{ICEVs}\ (2012\ to\ 2022) = 0.01$$

Apply the above formula,

$$CAGR_{BAU_{ICEVs}} = CAGR_{ICEVs}\ (2012\ to\ 2022) \times \frac{CAGR_{total\ vehicles}\ (2022\ to\ 2030)}{CAGR_{total\ vehicles}\ (2012\ to\ 2022)}$$

$$CAGR_{BAU_{ICEVs}} = 0.01 \times \frac{0.06}{0.02} = 0.038$$

$$ICEV_{2030} = 203 \times (1 + 0.038)^8 = 274$$

$$EV_{2030} = 368 - 274 = 94$$

Having arrived at the installed capacity/vehicle sales in the BAU scenario, capital expenditure was arrived at by multiplying the capital cost per unit with the installed capacity/vehicle sales.

4.2 Power Sector - Climate Finance Estimates

Historically, India has largely depended on fossil fuel-based sources of energy (coal and gas).8 Based on the projections made by the government of India, the total installed capacity of the power sector in India will rise from 406 GW in 2023 to 753 GW in 2030 at a CAGR of 9.2 per cent. At a disaggregated level, India's reliance on fossil-based power plants will reduce from 58 per cent in 2023 to 37 per cent in 2030, and that on non-fossil fuel-based power will increase to 63 per cent (Table 2), driven largely by solar energy (with its share projected to rise from 16 per cent of total installed capacity in 2023 to 39 per cent in 2030) and wind energy (from 11 per cent to 13 per cent). The remaining 11 per cent is constituted by nuclear, hydro and biomass. India's levelized solar and wind cost (the average cost of electricity generated over the lifetime of an energy asset) is amongst the lowest in the world, and both solar and wind technologies have become economically much more competitive relative to coal.9 The per-unit (MW) cost of installing solar power plants is less than one-half of that of a coal-fired power plant, and that of wind energy is about two-thirds relative to a coal-based power plant.

Table 2: Fossil and Non-fossil Fuel Sources of Power - Changing Pattern

(Installed Capacity in GW)

Installed Capacity - 2023				Projected Installed Capacity - 2030			
Fossil-Fuel	Non-Fossil Fuel	Total	Share of Non-Fossil in Total Installed Capacity (per cent)	Fossil-Fuel	Non-Fossil Fuel	Total	Share of Non-Fossil in Total Installed Capacity (per cent)
237	169	406	42	277	476	753	63

Source: Compiled by authors.

The projected installed capacity in the power sector, including coal-based and gas-based power plants, is estimated at 753 GW in 2030, which will produce 2,363 trillion-watt hours (TWH) of electricity. The plant load factor (PLF) – a measure of a power plant's capacity utilisation in relation to its installed capacity – for non-fossil fuel-based power plants is much lower than that of fossil fuel-based power stations. For instance, in India, the PLFs of solar and wind energy plants are 17 and 20 per cent, respectively, as compared with 63.7 per cent for coal-based power plants. In view of differences in PLFs of two conventional and non-conventional sources of power, the installed capacity of fossil fuel-based sources of power in the BAU was adjusted so that the total power generated based on official projections and the BAU was the same.

The projected installed capacity in 2030 is estimated to entail a total capex of US$628 billion in the power sector. However, in the BAU scenario, the total capex (based on adjusted installed capacity, as alluded to before) is estimated at US$581 billion in 2030. For the period 2024-2030, India is estimated to require an additional capex of US$47 billion for transitioning from fossil fuel-based sources of power generation to renewables. While the capex for fossil fuel-based sources of power is estimated to decline by US$43 billion during 2024-2030, that for non-fossil-fuel-based power sources would increase by US$90 billion (Table 3 and Appendix 1). However, apart from the capital cost of switching over sources of power, renewable sources of energy (RE) also entail additional capital costs for energy storage (Box 3).

Box 3: Integration and Storage Costs for Renewable Energy

Integration cost refers to the expenses involved in incorporating renewable energy sources into the power grid. These costs include enhanced coordination among stakeholders (power generating companies, distribution utilities, transmission companies, and power exchanges) and system operator, provision of ancillary services to manage the uncertainty and variability of renewables, transmission and distribution upgrades, and demand-side flexibility through demand response and time-of-use pricing, among others.

In the case of India, renewable energy generation capacity has expanded rapidly over the last two decades. With the country's ambitious targets for further expansion, the entire power generation sector must be equipped to tackle the challenges arising from the variability and uncertainty of renewable energy sources. These challenges are not limited to technical aspects alone; they also have significant financial implications. Key issues include:

- The need to maintain standby capacity to account for fluctuations in wind and solar power.
- The requirement for flexible generation systems that can quickly adjust to changes in renewable energy output.
- The impact on the States Deviation Settlement Mechanism (DSM) charges for inter-state power transfers.
- The effect on coal-based generation (including reduced efficiency and operation at lower plant load factors).
- The higher transmission costs associated with the lower capacity utilisation of wind and solar energy.

However, we have not considered the cost of integration in our analysis because it would require the building of several scenarios which are hard to envisage at this stage.

As the grid accommodates more renewable energy, ensuring stable operation will increasingly depend on storage solutions. Storage alleviates grid congestion and allows surplus renewable energy to be utilised during non-peak solar and wind periods. There are primarily two sources of energy storage: battery storage and pumped storage.

In 2023, battery storage emerged as the fastest-growing technology in the power sector, with its deployment more than doubling within a year. The global installed capacity of battery storage soared from approximately 1 gigawatt (GW) in 2013 to over 85 GW in 2023.

Currently, the global cost of a utility-scale battery with four-hour storage ranges from US$200/kWh to over US$300/kWh, with the most cost-effective projects located in China. According to the IEA, the capital costs of battery storage could decrease by up to 40 per cent by 2030 compared with 2022 levels, making battery storage combined with solar PV one of the most competitive electricity sources. Therefore, capital cost for battery storage is taken as the average cost for all the years from 2024 to 2030. However, capital cost for pumped storage is based on current cost.

The capital cost for battery storage for 2024–2030 is estimated at US$6 billion and for pumped storage at US$4 billion (Table 3.1).

Table 3.1: Estimate of RE Battery Storage Capex in India

	Installed Capacity (GW)			Capex (US$ Billion)			
Source	2023 (Actual)	Projected installed capacity - 2030	Installed Capacity in BAU - 2030	Capital Cost (US$ Million Per MW of Installed Capacity)	Capex based on projected installed capacity - 2024-2030	Capex based on the BAU scenario- 2024-2030	Additional Capital Expenditure - 2030
Battery Storage	0.04	42	32	0.68	22	16	6
Pumped Storage	4.78	19	14	0.78	11	7	4
Total	4.82	61	46	-	33	23	10

Source: Ministry of Power, India; Central Electricity Authority, India; and Centre for Science and Environment, India; and authors' calculations.

Energy storage costs (battery storage cost and pumped storage cost) for renewable energy are estimated to entail an additional capex of US$10 billion. Overall, it is estimated that India will require an additional capex of US$57 billion for 2024–2030 for transitioning to renewables, which works out to US$8 billion or 0.1 per cent of GDP annually (Table 3).

Table 3: Power Sector - Climate Finance Requirements

(Installed Capacity in GW; Amount in Billion US$)

Source	Installed Capacity-2023 (Actual)	Projected Installed Capacity-2030	Installed Capacity in BAU scenario-2030	Total Electricity Generated (TWH)		Capex based on projected Installed Capacity: 2024-2030	Capex based on the BAU Installed Capacity: 2024-2030	ACE 2024–2030	ACE Storage 2024–2030	ACE Total 2024–2030	ACE 2024–2030	ACE (per cent of GDP)
				Based on projected Installed Capacity-2030	BAU Scenario-2030						Annual Average	
1	2	3	5	7	8	9	10	11 = (9-10)	12	13 = (11+12)	14	15
Fossil	237	277	321	1,428	1,660	39	82	-43	-	-43	-6	-0.1
Non-fossil	169	476	358	935	703	221	131	90	10	100	14	0.2
Total	**406**	**753**	**679**	**2,363**	**2,363**	**260**	**213**	**47**	**10**	**57**	**8**	**0.1**

Note: 1. The estimates for the power sector in this study are based on coal-based and gas-based power stations, which constitute 97 per cent of thermal-based installed capacity. The other 3 per cent thermal installed capacity is constituted by lignite and diesel.
2. The storage capex is based on the battery storage and pumped storage for the period from 2024 (installed capacity) to 2030 (projected installed capacity). ACE- Additional capital expenditure.
Source: Central Electricity Authority (CEA), India; and authors' calculations.

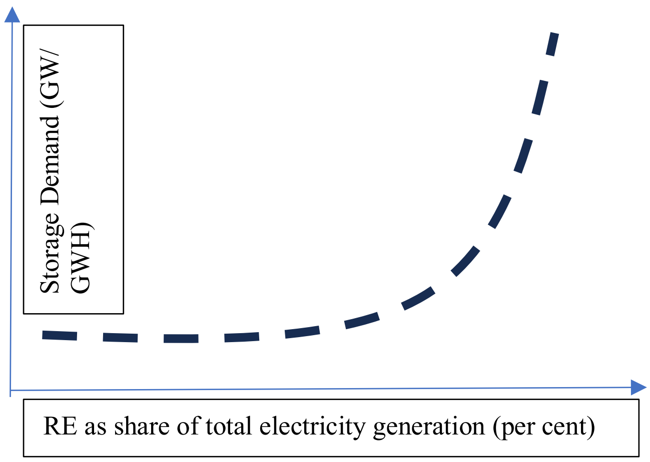
The power sector presents unique cost dynamics in emission reduction efforts mainly due to the costs of integrating renewable energy sources with the main power grid and the need for energy storage. An important characteristic of the power sector's decarbonisation trajectory is the non-linear relationship between storage needs and the RE share in total electricity generation (Box 4).

Box 4: Battery Storage and Investment Dynamics - Power Sector

Non-Linearity in Storage Requirements

The demand for energy storage in India is expected to increase sharply as the share of electricity generated through renewable sources in total electricity increases in the long run (Figure 4.1).

Figure 4.1: Non-Linearity in Storage Requirements



Source: Authors' representation.

The curve indicates two distinct phases:

1. Initial Phase (Flat Curve at the Bottom):

- At low levels of RE penetration, storage demand remains relatively low.
- This is because conventional power sources, such as coal and gas, continue to provide flexibility to the grid, obviating the need for large-scale storage.

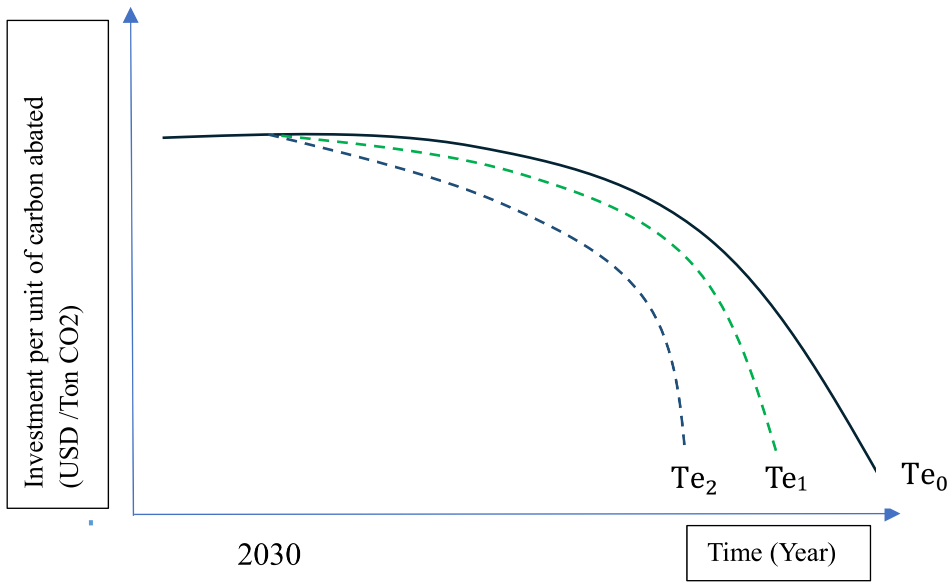
2. Rapid Growth Phase (Steep Section):

- As the share of RE increases beyond a certain threshold, storage demand rises sharply.
- This happens because sources like solar and wind require significant energy storage to balance fluctuations in power supply and demand.
- During this phase, investments in battery energy storage systems (BESS) and pumped storage plants (PSP) are also expected to accelerate.

Investment Per Unit of Carbon Abated in Power Sector

Investment per unit of carbon abated (US$/Tonnes CO_2) is expected to decline rapidly over time. Even assuming no further technological improvements, the investment per unit of carbon abated is expected to decline as the scale of renewable increases, driving down the per unit cost (Figure 4.2). For the period up to 2030, it has been assumed that there will not be any change in the investment per unit carbon saved (Figure 4.2).

Figure 4.2: Investment per unit of Carbon Abated



Source: Authors' representation.

However, should there be technological improvements, the investment per unit carbon abated should decline depending on the time period when they take place (Te_0, Te_1, Te_2, or any other time period).

The transitioning from fossil fuel-based sources of power to renewables mitigates carbon emissions. However, so long as fossil fuel-based power plants exist, they will continue to emit CO_2. To mitigate such CO_2, the only feasible technology is Carbon Capture and Storage (CCS). The capex for using CCS for the power sector has also been estimated to give an idea of the magnitude of capex required for using CCS for the power sector (Appendix 2). However, we have not considered CCS capital expenditure for the power sector due to its high cost, parasitic load and the availability of cost-effective renewable alternatives (Box 5).

Box 5: Why is CCS Technology not used in the Power Sector?

Carbon Capture and Storage (CCS) is a critical technology designed to capture CO_2 emissions from industrial processes and power generation and prevent their release into the atmosphere by storing them in distant geological locations (see also Box 7). However, its adoption varies significantly across sectors. While CCS is being increasingly used in hard-to-abate sectors such as steel and cement, its deployment in the power sector remains limited due to economic constraints, energy penalties and the availability of alternative decarbonisation strategies.

One of the primary reasons for the limited adoption of CCS in the power sector is its high cost. Integrating CCS into power plants requires significant capital investment for installing carbon capture equipment, transportation pipelines, and storage facilities.

Another critical challenge is the energy penalty associated with CCS. The process of capturing and compressing CO_2 is highly energy-intensive itself, leading to a "parasitic load" that reduces the net electricity output of power plants. This efficiency loss increases fuel consumption, further escalating operational expenses and potentially offsetting some of the environmental benefits (Rubin et al., 2012).

Yet another reason why CCS is not used in the power sector is the availability of cost-effective renewable alternatives such as solar and wind. The relative significance of fossil fuel sources of power in many countries has declined in recent years, and it is expected to come down further going forward. As alluded to before, the share of installed capacity of fossil-fuel based sources in total installed capacity in the power sector in India is projected to decline to 37 per cent in 2030 from 58 per cent in 2023. It is also significant that the per unit cost of power generation from renewables has declined sharply in recent years. It, therefore, makes far better sense to expand quickly the use of renewables rather than incur large capital expenditure on CCS technology for benefits of which will only be available for a limited number of years while fossil fuel power is phased out.

In contrast, steel and cement production and the associated CO_2 emissions are expected to continue to rise as the global economy expands, particularly in emerging markets and developing economies. These industries still have limited alternatives for decarbonisation such as the prospects of achieving energy efficiency and using alternative fuels. Hydrogen-based steelmaking and alternative cement formulations are being explored, but they are not yet commercially viable at scale (see also Box 7). Therefore, CCS remains one of the few feasible options for reducing emissions in the cement and steel sectors (IEA, 2021).

4.3 Transport Sector—Climate Finance Estimates

In 2022, 20 million ICEVs pieces were sold in India, constituting 94 per cent of total vehicles (ICEVs and EVs) sold. Two-wheelers dominated the market with a share of 78.1 per cent in total ICEV sales in 2022, followed by four-wheelers (share of 14.6 per cent). The remaining 7.3 per cent share was constituted by three-wheelers, buses and trucks/goods vehicles. However, India is rapidly moving towards expanding its fleet of EVs. Though the sales of ICEVs are projected to rise to 24 million units by 2030, their share is projected to decline to 66 per cent in all vehicles. Sales of EVs are projected to rise to 12 million units, with their share in total vehicles projected at 34 per cent, mainly due to a sharp increase in the sales of electric two-wheelers (Table 4). EV two-wheeler sales are projected to rise sharply from 0.7 million units in 2022 to 10.5 million units by 2030. EV four-wheeler sales, though modest in 2022 at 48,000 units, are projected to reach 0.6 million units by 2030 (Appendix 3).

Table 4 : ICEVs and EVs - Changing Pattern

(*Vehicle Sales in thousands*)

ICEV Sales		**EV Sales**		**Total Vehicle Sales**		**Share of EVs in total vehicles (per cent)**	
2022 (Actual)	2030 (projection)	2022 (Actual)	2030 (projection)	2022 (Actual)	2030 (projection)	2022 (Actual)	2030 (projection)
20,314	24,303	1200	12,492	21,515	36,794	6	34

Source: NITI Aayog and Bain and Company.

In the BAU scenario, the number of ICEVs is estimated to grow at a higher rate of 3.1 per cent than projected (2.3 per cent) and EVs at a lower rate of 31.7 per cent than projected (34 per cent), though the total number of vehicles would remain unchanged. Accordingly, in the BAU scenario, the share of ICEVs is estimated at 70 per cent in 2030 as against the projected share of 66 per cent, while that of EVs is at 30 per cent as against the projected share of 34 per cent.

Table 5: Road Transport Sector - Climate Finance Requirements

(Vehicles in '000; Amount in billion US$)

Vehicle Type	Vehicles Sold in 2022	Projected Sales - 2030	Capex based on projected sales of vehicles-2030	BAU Sales - 2030	Capex based on vehicle sales in the BAU scenario-2030	ACE - 2030	ACE 2023-2030	Charging Infrastructure ACE 2023 - 2030	Total ACE 2023-2030	Total ACE	Total ACE per cent of GDP
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
										Annual Average	
ICEVs	20,314	24,303	124	25,894	132	-8	-31	-	-31	-3.9	-0.07
EVs	1,200	12,492	85	10,901	74	11	41	8	49	6.1	0.11
Total	**21,515**	**36,794**	**209**	**36,794**	**206**	**3**	**10**	**8**	**18**	**2.2**	**0.05**

ACE: Additional Capital Expenditure; ICEVs: Internal Combustion Engine Vehicles; EVs: Electric Vehicles.
Note: Some totals may not add up due to rounding of figures.
Source: NITI Aayog; Bain and Company; and authors' calculations.

The capex for the road transport sector based on the sales of vehicles projected for 2030 is estimated at US$209 billion. However, in the BAU scenario, the capex for 2030 has been estimated at US$206 billion. As a result, the ACE for road transport works out to US$3 billion for 2030. The ACE required for the electrification of vehicles (the switchover from ICEVs to EVs) is estimated at US$10 billion from the period from 2023 to 2030. In addition, it is estimated that India would need a capex of US$8 billion for developing the charging infrastructure for EVs (Box 6). Overall, capex for road transport is estimated at US$18 billion from 2023 to 2030, or US$2.2 billion annually (0.05 per cent of GDP) – Table 5.

Box 6: Cost of Developing Charging Infrastructure in India

India is pursuing a rapid electrification of its road transport sector, which requires a large number of charging stations. The global norm is one charging station for 6 to 20 EVs. However, the existing ratio for India is much lower at one charging station for 135 EVs. As of the end of 2022, India had installed 7,005 charging stations (Government of India, 2023). The Confederation of Indian Industry (CII) estimated that India would need approximately 1.32 million charging stations by 2030 to cope with the rapid electrification of vehicles, translating to 4 lakh charging stations per year. This will help achieve India 1 charging station for 40 EVs, *i.e.,* ratio of 40:1 (IANS 2024).

The cost of setting up a charging station In India is in the range of US$35,000–US$58,000. In addition, there will also be installation/infrastructure costs (Table 6.1).

Table 6.1: Infrastructure cost of a charging station

Key Areas	Cost (US$)
New Electricity Connection	8,716
Civil Work	2,324–5,812
EVSE Management Software + Integration Cost	581–1,743
Technician and Manpower along with the Maintenance Costs	4,068
Advertising and Promotion	2,905–5,812
Land Lease	6,973–11,622

Note: EVSE: Electric Vehicle Supply Equipment.

Source: Data sourced from Cars24, India were converted into US$ at the current exchange rate (US$1 = Rs 86).

In terms of the requirements prescribed by the Ministry of Power in December 2018, a charging station must contain at least two slow/moderate speed and three fast-speed chargers. The cost of different types of chargers is as follows:

Table 6.2: Cost of Chargers

Charger Connector	Type of charger	Cost (US$)
Bharat AC–001	Slow/Moderate	756
Bharat DC–001		2,872
Type 2 AC	Fast	1,395
CHAdeMO		15,965
Combined Charging System (CCS)		16,276

Note: CHAdeMO: CHArge de MOve.

Source: Data in Rupees sourced from Acharya M., Clear Tax, 2024 were converted into US$ at the current exchange rate (US$1 = Rs 86).

For the purpose of our analysis, we have considered only three types of chargers (Bharat AC – 001; Bharat DC – 001; and Type 2 AC).

Steel and Cement Sectors – Methodology for Estimating Capital Expenditure

Steel and cement are hard-to-abate sectors due to their energy-intensive and emission-intensive production processes. Decarbonising these sectors requires a diverse range of low-carbon solutions and systematic changes in the way materials are produced, used, and combined. Various decarbonisation options include energy efficiency, renewable energy, alternative fuels, carbon management, and clinker substitution (for making cement) - Box 7.

Box 7: Different Pathways for Decarbonisation - Steel and Cement

Energy efficiency methods aim at reducing energy consumption and increasing waste heat recovery and lowering emission intensity without significant process changes. However, further improvements are limited with current technology (South African Iron and Steel Institute, n.d).

In the cement industry, alternative fuels like biomass, waste fuel and green hydrogen have lower carbon intensities than traditional fossil fuels, but offer limited reduction potential, ranging from 1–18 per cent (Hasanbeigi & Bhadbhade 2023). Kiln electrification involves switching to renewable energy sources and can potentially reduce about 40 per cent of thermal emissions from cement production (Aggarwal 2024). Clinker, responsible for 60–65 per cent of cement manufacturing emissions, can be partially replaced with substitutes like steel slag and fly ash, though this depends on local availability and the desired properties of the final concrete (Cembureau n.d.).

In the steel sector, the energy efficiency and the use of alternative fuels, as discussed above, has a limited effect on overall emission reduction as the production process is highly energy intensive and inherently reliant on chemical reactions that release significant amount of CO_2. While each of the methods can reduce the emissions by a certain per cent, carbon capture utilisation storage (CCUS) offers the most effective method for emission reduction (Elango et al., 2023).

CCUS is a set of technologies that capture, transport, and store or utilise CO2. This process can be retrofitted to existing emission sources, capturing CO2 from large point sources like industrial facilities before it enters the atmosphere. The captured CO2 is then compressed and transported, typically via pipelines or ships, to storage or utilisation sites. Storage involves injecting CO2 into geological formations, while utilisation can include creating products like construction materials or synthetic fuels, though these pathways have limited capacity compared to geological storage.

The latest report by Intergovernmental Panel on Climate Change (2022) emphasises the necessity of deploying CCUS technologies to achieve net-zero CO2 or GHG emissions, particularly to counterbalance residual emissions that are difficult to abate. CCUS is crucial for reducing both process and thermal emissions in industries like cement and steel, where conventional methods fall short.

Despite being capital- and energy-intensive, CCUS is considered the most feasible option for large-scale industrial decarbonisation. However, the cost of carbon capture varies greatly based on the source of CO2. The costs also vary by region but are expected to decrease with technological advancements across regions and industries (LSE, 2023; Evans, 2021). Currently, CCUS has a capture rate of 90 per cent and globally captures about 50 million tonnes of CO2 annually, representing 0.1 per cent of global emissions (Lebling et al., 2023). By 2030, global carbon capture capacity is expected to increase six-fold, offering significant opportunities for developing countries to adopt CCUS technologies and advance decarbonisation in hard-to-abate sectors (Bloomberg, 2022).

The use of green hydrogen in energy-intensive industries such as steel and cement production offers a potential pathway for decarbonisation, either as a substitute for traditional fuels or in carbon management through CCU. However, both applications face distinct challenges. Switching from conventional fuels like petroleum coke (petcoke) to hydrogen requires substantial technical adjustments in these industries. The integration of hydrogen as a fuel demands significant alterations to existing production set-ups, including advancements in metallurgical techniques and combustion systems (Nitturu et al., 2023). On the other hand, green hydrogen can be used in carbon management by combining it with captured CO_2 to produce synthetic fuels via methanation. This enables the utilisation of CO_2 for industrial applications. However, the high cost of green hydrogen production poses a major obstacle. Its cost in India ranges from US$3.6 to US$5.8 per kg. Though it is expected to drop to US$2 per kg by 2040, it may still remain economically unviable for widespread adoption compared to storage technologies (Tirtha et al., 2020). Furthermore, the slow rate of infrastructure development for hydrogen production and distribution continues to delay its broader adoption, even globally (IEA, 2019).

India's dependency on fossil-based energy resources is likely to continue in the future unless there are some unexpected technological innovations that reduce the role of fossil fuel energy in these sectors; hence, a CCUS policy in the Indian context is a must (NITI Aayog, 2022). This highlights the critical importance of integrating CCUS technologies to mitigate carbon.

A consistent methodology has been used in this study to arrive at the capex for decarbonising the steel and cement sectors through various pathways (Box 8). This study concentrates on the costs of CCS, excluding utilisation, for the reason that utilisation costs are not only significantly higher but also highly variable depending on the end product or application, which are not known at this stage. Consequently, this study focusses on the more straightforward and better-documented CCS cost.

Box 8: Methodology for Estimating Capex - Cement and Steel Sectors

This study aims at estimating the capex required between 2022 and 2030 to reduce carbon emissions in India's steel and cement sectors. The methodology is applied uniformly across both the sectors. Following steps were undertaken to arrive at the required capex:

1. Estimating Capex for Pathways (Other than CCS):

While CCS is the main approach for carbon reduction in the steel and cement sectors, about one-third of emissions can be mitigated through alternative pathways. These include enhancing energy efficiency, increasing renewable energy usage, adopting alternative fuels and reducing the clinker factor in cement production. The estimates for emission reductions *via* these pathways are sourced from studies Nitturu *et al.,* 2023 and Elango *et al.,* 2023. The following table sums up the percentage contributions of each pathway and the corresponding capex per unit of emission reduction:

Table 8.1: Reduction of Carbon Emissions and Capex per Unit of Emission

	Reduction of Carbon Emissions (per cent)		Capex per Unit of Emission (US$)	
Pathways	Cement	Steel	Cement	Steel
Energy Efficiency	9	9	147	437
Renewable Energy	3	19	806	239
Alternative Fuels	10	6	27	1119
Reduction in Clinker Factor	11	-	227	-
CCS	67	66	608*	483*

*See section 2 of the box.

Source: Authors' calculations.

The above-mentioned percentages were used to estimate the achievable emission reductions for each pathway. The capex per unit of emissions was applied to calculate the total capex required for each pathway.

2. Estimating Per Unit Capex for the CCS Pathway:

- The per-unit emission capture and storage (CCS) cost for the cement and steel sectors was taken from different published and reliable sources as no single source provided comprehensive cost estimate (Appendix Table A5.1.).
- The CCS costs obtained from various sources did not consistently include transportation and storage components. Where these components were missing, appropriate estimates were added to the CCS costs, using the transportation and storage costs for different countries from the study by Smith *et al.*, 2021.
- The following formula based on a study by (Qiao *et al.*, 2023) was used to calculate the capex required to mitigate one unit of CO_2 through the CCS pathway:

$$\text{Per unit capital cost of CCS} = \frac{(Capture\ Cost\ 2022 + Storage\ Cost\ in\ 2022 + Transport\ Cost\ in\ 2022)}{(CRF + OPEX\%)}$$

where: capture cost, storage cost and transport cost are the annualised cost per unit of emission; CRF: Capital Recovery Factor; OPEX= Operational expenditure.

- The capital recovery factor has been arrived at based on the following assumptions:
  - Average plant life (for steel and cement): 25 years
  - Interest rate: 10 per cent
  - Operational Expenditure (OPEX): 5 per cent of Total capex

Capital Recovery Factor (CRF) which is used to annualise the total capex over the lifetime of a project and taking prevailing interest rate was calculated using the formula $\frac{i(1+i)^n}{(1+i)^n - 1}$. This is because CCS costs are often reported on an annualised basis, while capex is a one-time investment. The CRF allows us to convert a series of future cash flows (annualised costs) into an equivalent present value (initial capex). That is, the CRF is crucial for translating the total annualised costs (which includes both capital and operational components) into the initial capex required.

Where:

i= interest rate (10 percent)

n= number of years (plant life) – 25 years

An illustration:

$$\text{Capital Recovery Factor (CRF)} = \frac{(0.10)(1+0.10)^{25}}{(1+0.10)^{25} - 1} = 0.1102 \text{ or 11 per cent}$$

T

he annualised capture cost for steel and cement has been taken as the global average of US$70 per tonne of CO_2 and US$90 per tonne of CO_2, respectively, as the India-specific costs were unavailable (Nitturu *et al.,* 2023 and Elango *et al.,* 2023). The cost per unit increases to US$77.43

for steel and US$97.43 for cement after considering the storage and transportation costs, as detailed below:

Steel sector:

$$\text{Per unit cost of CCS} = \frac{(70+1.19+6.24)}{(0.1102+0.05)} = \text{US\$483 per tonne of } CO_2$$

Cement sector:

$$\text{Per unit cost of CCS} = \frac{(90+1.19+6.24)}{(0.1102+0.05)} = \text{US\$608 per tonne of } CO_2$$

- The total capex for each sector over the 2022-2030 period was then calculated by summing the capex from each pathway across all years.

This methodology provides a detailed approach to estimating the financial investments needed to reduce carbon emissions in India's steel and cement sectors.

4.4 Steel Sector - Climate Finance Estimates

Steel production primarily uses two methods: Basic Oxygen Steelmaking (BOS) and the Electric Arc Furnace (EAF). BOS uses molten pig iron, steel scrap and oxygen to produce steel, while EAF mainly relies on recycled steel scrap melted using electric arcs. EAF is considered more environmentally friendly due to its use of recycled materials and lower emissions. However, BOS remains the dominant method globally, accounting for about 70 per cent of steel production in 2021. This is largely due to existing infrastructure, raw material availability, and suitability for large-scale production in many countries. Nevertheless, EAF is gaining ground, with its share globally increasing from 25 per cent in 2012 to 30 per cent in 2021, producing around 560 million tonnes of steel (Kumar, 2024). The shift was particularly notable in regions like the United States and the European Union, where the shares of EAF steel production were at 71.8 per cent and 44.8 per cent, respectively, in 2023. This growth reflects a gradual shift towards more sustainable steelmaking processes, driven by environmental concerns and the increasing availability of steel scrap. Most steel-producing economies primarily use steel scrap in EAFs, making it a less carbon-intensive process.

India, with an output of 125 million tonnes of crude steel in 2022, ranks as the world's second-largest producer, accounting for 6.7 per cent of global production. At present, the steel sector contributes about 2 per cent to India's GDP. About 46 per cent of the crude steel in the country is produced from the Blast Furnace-Basic Oxygen Furnace (BF-BOF) route, while 54 per cent is produced through EAF and induction furnaces.

India relies heavily on coal-based sponge iron and direct reduced iron (DRI) and less on steel scrap as the scale of its steel production is large and expanding. The production of DRI is highly energy-intensive, resulting in higher CO_2 emissions compared to scrap-based production in EAFs. Approximately 50 per cent of the feedstock in Indian EAFs is DRI, with steel scrap playing a smaller role due to limited availability (Hasanbeigi, 2022).

Several major Indian steel companies, including Tata Steel, JSW Steel, Jindal Steel and Power, and ArcelorMittal Nippon Steel (AM/NS), have established EAFs, thereby shifting to a less carbon-intensive production process (Kumar, 2024). However, the reliance on carbon-intensive feedstocks means that even these more modern production processes contribute significantly to India's high CO_2 emissions in the steel sector. Owing to the predominance of such emission-intensive production routes, the Indian steel sector has one of the highest emission intensities at 2.4 tonnes of CO_2 per tonne of crude steel (tCO_2/tcs) as against the global average emission intensity of only 1.85 tCO_2/tcs (Garg *et al.*, 2023).

The existing total steel production of 125 million tonnes as in 2022 is estimated to require a total capex of US$140 billion to decarbonise it, comprising US$95 billion through CCS and US$45 billion through other pathways such as energy efficiency, renewable energy, and alternative fuels. The government of India (GOI) projects crude steel production at 225 million tonnes in 2030, effectively doubling production from the 2022 level. Beginning 2023, capex to decarbonise the steel sector would be required only for incremental steel produced and the concomitant CO_2 emissions. Assuming the existing carbon emission intensity, the projected production for 2030 would result in an increase of 80 per cent in emissions by 2030 to reach 533 million tonnes of CO_2. The mitigation of this level of CO_2 will require a total capex of US$251 billion, consisting of US$170 billion through CCS and US$81 billion through other pathways. This, on average, works out to US$28 billion or 0.7 per cent of GDP annually (Table 6).

Although India's climate finance across years is significantly lower than that of China, which has the highest estimated climate finance in absolute amount, India's climate finance for the steel sector as a per cent of GDP is the highest among the G20 emerging economies because of its large production size and significantly high carbon intensity (Raj & Mohan, 2025). This indicates the substantial financial burden associated with decarbonising the steel sector.

Table 6: Steel Sector - Climate Finance Requirements

Year	Production	Incremental Emissions	Required Capex: CCS	Required Capex: Other Pathways				Total Required Capex	Total Capex Average (2022-30)	Total Capex as share of GDP
				Energy Efficiency	Renewable Energy	Alternate fuels	Total			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) = (5 to 7)	(9) = (4+8)	(10)	(11)
	Million Tonnes		US$ Billion							Per cent
2022	125	297	95	12	13	20	45	140	-	-
2030	225	38	12	1	2	3	6	18	-	-
Cumulative (2022–2030)	**1538**	**533**	**170**	**21**	**24**	**36**	**81**	**251**	**28**	**0.7**

*Average (2022-30).

Source: Authors' calculations.

4.5 Cement Sector–Climate Finance Estimates

Cement production primarily employs two methods: wet and dry. The wet method is more carbon-intensive due to its higher energy requirements for water evaporation during the production process. In contrast, the dry method is more energy-efficient and environmentally friendly. Now using more efficient furnaces (high-efficiency kilns) with advanced heating systems, Indian cement plants have greatly improved their technology. Currently, almost 99 per cent of India's installed cement manufacturing capacity uses the dry process, which is less carbon-intensive (Cement Manufacturing Association, 2021). Despite the widespread adoption of the more efficient dry method in India's cement industry, the carbon intensity of cement production has not been reduced to its full potential. This is primarily due to two factors: a heavy reliance on coal for both power generation and as a fuel source in cement kilns, and the limited use of alternative fuels on a large scale.

The types of cement produced in India significantly impact its carbon intensity profile. The production breakdown reveals that Pozzolana Portland Cement (PPC) dominates the market, accounting for 65 per cent of production with a clinker content of about 70 per cent. Ordinary Portland Cement (OPC) follows, making up 27 per cent of production and containing a high clinker content of approximately 95 per cent. Portland Slag Cement (PSC) represents the smallest share at 7 per cent of production, but it has the lowest clinker content at 40–45 per cent, making it the least carbon-intensive option. The prevalence of PPC and OPC, which have higher clinker content, contributes to the overall carbon intensity of India's cement production. The carbon intensity of cement in India of 0.44, however, is lower than the global average of 0.68.

India is the second-largest producer of cement in the world, producing about 370 million tonnes of cement in 2022. By 2030, its cement production is projected to rise by 82 per cent to 674 million tonnes, at which point it will account for 18 per cent of global cement production, as against 9 per cent in 2022. India's carbon emissions from cement were 164 million tonnes in 2022, and with the same carbon emission intensity, the emissions in 2030 would increase to 300 million tonnes.

To abate these emissions, pathways like energy efficiency, renewable energy, alternative fuels, reduction in the clinker factor and CCS would be required. Nitturu *et al.* (2023) suggest that more than half of the emissions are produced due to the calcination of limestone in the kilns, followed by the combustion of fuels for process heating applications and the electricity used for manufacturing. Though pathways like energy efficiency, renewable energy and alternative fuels can contribute to emission reductions in the cement sector, their potential is limited as they do not impact the calcination process. On the other hand, CCS can capture the CO_2 emissions from the calcination process and any other combustion sources in cement plants (Nitturu *et al.*, 2023). For mitigating all emissions till 2022 using different pathways simultaneously, the total capex is estimated at US$78 billion in 2022. As in the case of the steel sector, additional capex would also be required for mitigating incremental CO_2 emissions resulting from increased cement production, which is projected to rise to 674 million tonnes in 2030. The total capex required for the cement sector through all the pathways has been estimated at US$141 billion up to 2030. This, on average, works out to US$16 billion annually or 0.4 per cent of GDP (Table 7).

Table 7: Cement Sector - Climate Finance Requirements

Year	Production	Incremental Emissions	Required Capex: CCS	Required Capex: Other Pathways					Total Required Capex	Total Capex Average (2022-30)	Total Capex as share of GDP
				Energy Efficiency	Renewable Energy	Alternate fuels	Clinker Factor Reduction	Total			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9) = (5 to 8)	(10) = (4+9)	(11)	(12)
	Million Tonnes		US$ Billion								Per cent
2022	370	164	67	2.2	4.0	0.4	4.1	11	78	-	-
2030	674	22	9	0.3	0.5	0.1	0.5	1	10	-	-
Cumulative (2022–2030)	**4581**	**300**	**122**	4	7	1	7	**19**	**141**	**16**	**0.4**

*Average from 2022 to 2030.
Source: Authors' calculations.

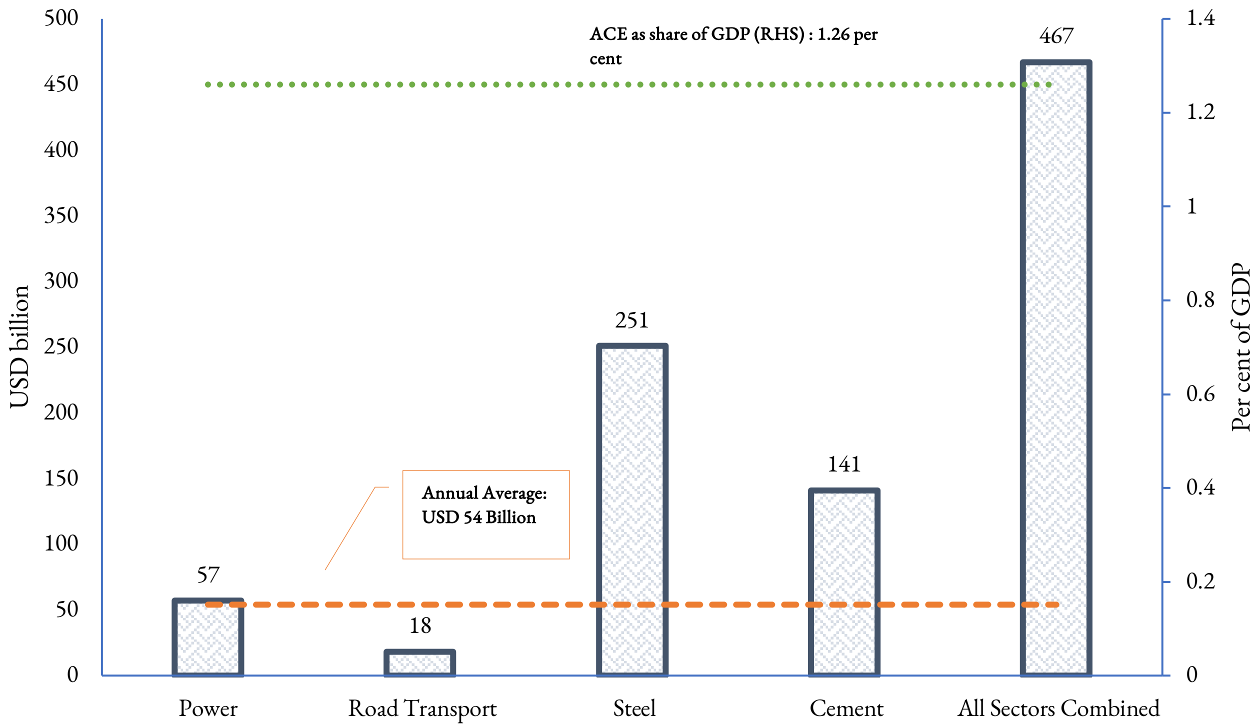
4.6 Overall Climate Finance Estimates for India in Four Key Sectors

The overall estimated climate finance requirements for India's four key CO_2-emitting sectors – power, transport, steel, and cement – are estimated at US$467 billion (at current prices) from 2022–2030,[10] with an annual average capex of US$54 billion, or 1.3 per cent of India's GDP. Of this, US$392 billion is estimated for the two hard-to-abate sectors: steel (US$251 billion) and cement (US$141 billion). The bulk of CO_2 emissions in these two sectors can be abated mainly by using CCS technology, which is expensive but the only effective technology option available at present.

India is estimated to require US$47 billion for switching from fossil fuel-based sources of power to renewables. The unit capital cost for setting up renewables (installed capacity) is now markedly lower than that of coal-fired power plants. Relative to conventional energy sources, the capital unit cost of solar energy is about one-half, and that of wind energy is about one-third. Renewables, however, also entail additional capital costs of storage.[11] The cost for battery storage for 2024–2030 is estimated at US$6 billion and for pumped storage at US$4 billion. After including the storage costs, India will require a capex of US$57 billion as additional capital expenditure for the power sector for 2023–2030.

India is estimated to require US$10 billion for the electrification of its road transport vehicle fleet up to 2030. In addition, there will also be a need for an additional capex of US$8 billion to develop the charging infrastructure for EVs. Including this, the additional capital expenditure for road transport is estimated at US$18 billion for the transport sector (Figure 6).

Figure 6: Additional Capital Expenditure for India: 2022 - 2030



ACE: Additional Capital Expenditure

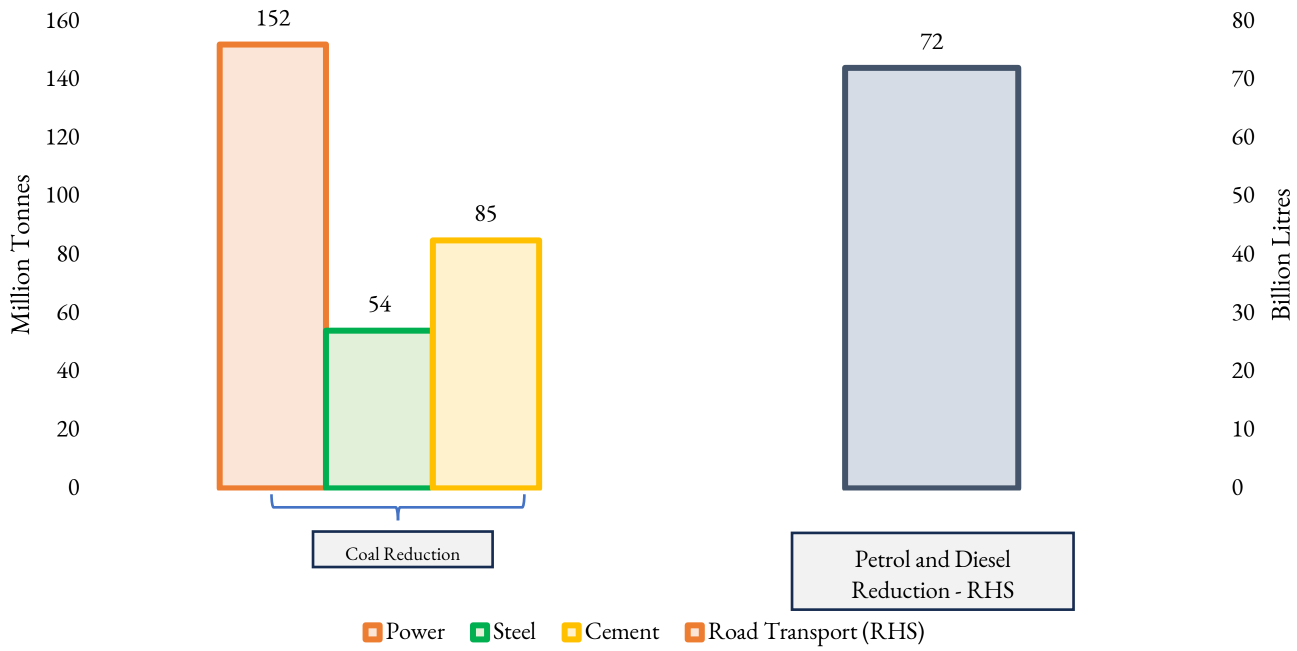
Note: The period is 2022–2030 for the steel and cement sectors, 2024–2030 for the power sector, and 2023–2030 for road transport.

Source: Authors' calculations.

Based on the above estimates, the decarbonisation of the four sectors would result in a large reduction in the use of fossil fuel of 291 million tonnes of coal (152 million tonnes in the power sector, 85 million tonnes in the cement sector and 54 million tonnes in the steel sector) and 72 billion litres of petrol and diesel in the road transport sector (Figure 7).

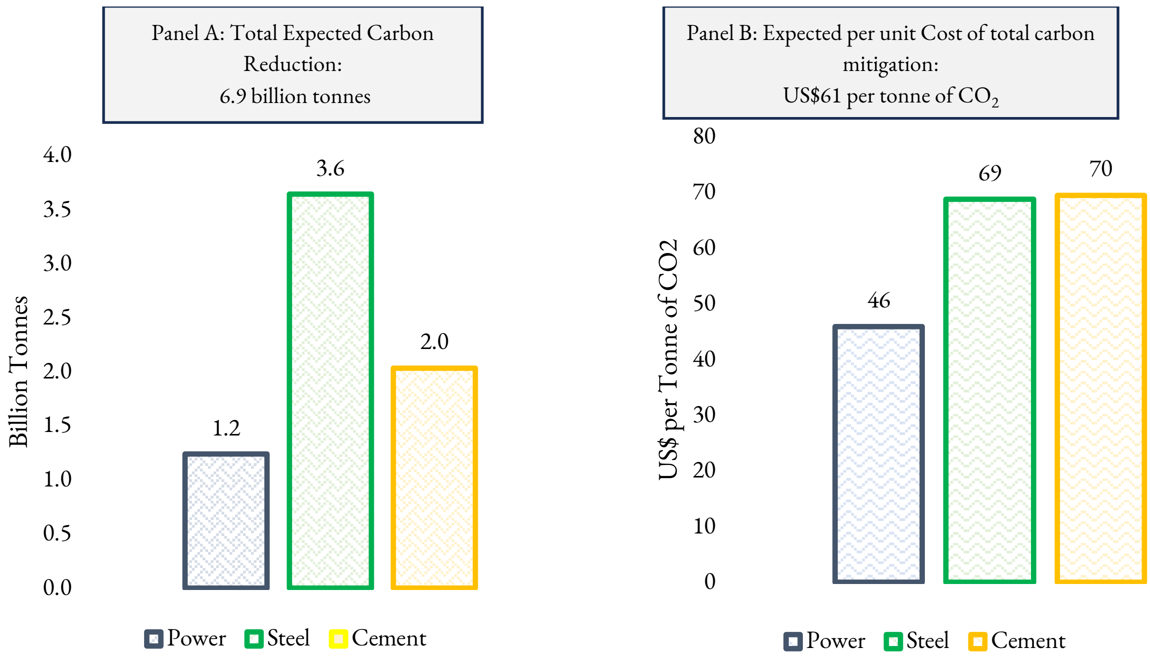
The estimated climate mitigation investment up to 2030 in three sectors (power, steel, and cement[12]) is expected to cumulatively mitigate 6.9 billion tonnes of CO_2, most of which will be in the steel and cement sectors (Figure 8, Panel A). The average cost of mitigating CO_2 emissions in the three sectors works out to be US$61 per tonne of CO_2. The per-unit cost of abating CO_2 is the largest for the cement sector (US$70 per tonne of CO_2), followed by steel (US$69) (Figure 8, Panel B).

Figure 7: Expected Reduction in the Use of Fossil Fuel: 2022- 2030



Note: The period is 2022–2030 for the steel and cement sectors, 2024-2030 for the power sector and 2023-2030 for road transport.
Source: Authors' calculations.

Figure 8: Expected CO_2 Emissions Reduction and Per-Unit Cost of Carbon Mitigation



Note: The period is 2022–2030 for the steel and cement sectors and 2024–2030 for the power sector.
Source: Authors' calculations.

It is significant to note that the cement sector in India is predominantly privately owned, with only one company (Cement Corporation of India) operating in the public sector. Steel plants are also largely in the private sector, manufacturing 83 per cent of crude steel production in the country; the remaining 17 per cent is manufactured by three public sector enterprises (PSEs): Steel Authority of India Ltd, National Mineral Development Corporation (NMDC) Steel Ltd and *Rashtriya Ispat Nigam* Ltd. Therefore, the investment requirements in the steel and cement sectors are expected to be mainly driven by private sector companies. This implies that the government's role in these two sectors will be to provide an appropriate incentive framework to encourage these industries to adopt low-carbon technologies. In addition, the government should also initiate a public-private programme of R&D to find technologies that progressively reduce CCS costs.

The climate finance estimates for the steel and cement sectors fully mitigate CO_2 in these two sectors, *i.e.,* CO_2 emitted till 2022 as well as the incremental CO_2 that will be emitted every year up to 2030.

Similarly, the road transport sector is owned and operated largely by the private sector. Consequently, the investment required for transitioning to greener technologies such as EVs will largely come from the private sector. The government's role in this sector would primarily be to provide subsidies and incentives to promote the adoption of EVs. However, much of the investment needed for charging infrastructure will need to be provided by the government, supplemented by private investment, as is the case with petrol stations.

In the power sector, while there is a mix of private and public sector involvement, a large portion (two-thirds) of thermal capacity is operated by PSEs (central and state). Thus, in the power sector, the general government may have to play a significant role in providing incentives and regulatory support to facilitate the transition to renewable energy sources.

5. Macroeconomic Consistency of Climate Finance Estimates

In this section, we assess the macroeconomic consistency of the estimated climate finance flows that will be needed in India. The macroeconomic consistency of climate finance estimates essentially means how far such flows from external sources can be absorbed/managed without impinging on the macroeconomic fundamentals of the economy, such as export competitiveness and/or domestic inflation.

5.1 Evolution of Key Variables in India—Business-as-Usual Scenario

As it is, capital and financial flows over and above the current account deficit need to be managed (Box 9). Therefore, climate finance flows from external sources over and above the capital and financial flows in the BAU scenario would need to be managed skilfully on a macro-consistent basis.

Otherwise, they could affect the exchange rate and domestic liquidity, with attendant implications for export competitiveness and inflation.

Box 9: Managing Capital and Financial Flows

A country needs capital flows to finance the gap between domestic savings and investment, as reflected in the current account deficit (CAD). Capital flows over and above the CAD cannot be absorbed in the domestic economy, but if bought by the central bank they can be added to its foreign exchange reserves to the extent that its balance sheet needs to expand consistent with the expansion in monetary base as the economy grows.

If excess capital flows are not properly managed, the exchange rate will appreciate which will make the economy uncompetitive. On the other hand, if there is excess intervention in the forex market then it could lead lead to an increase in domestic liquidity, which could be inconsistent with the required increase in monetary base or reserve money required for the growing economy.13 If an expansion in domestic liquidity is higher than the required increase in monetary base, it may require sterilisation as unsterilised intervention on a large scale can lead to a surfeit of liquidity with attendant implications for domestic inflation, rise in domestic interest rates, widening of the interest rate differential and the risk of further capital inflows, thereby defeating the very purpose of unsterilised intervention. Therefore, emerging market central banks often undertake sterilised intervention.

However, there are limits to sterilised intervention, which, among others, is determined by the stock of government securities held by the central bank in its portfolio. Therefore, several other instruments have also been used by central banks with varying degree of success. For instance, India introduced Market Stabilisation Scheme (MSS) in April 2004, when India received large capital inflows during 2003–2008.14

Forex market intervention has other implications as well. Increased forex market intervention also means increased share of net foreign assets (NFAs) in the central bank balance sheet. A larger share of NFAs also implies a corresponding decline in net domestic assets (NDAs), which can constrain market-based liquidity absorption operations. In the face of persistently large liquidity, this constraint could become binding (Raj et al., 2018). A relatively large share of NFAs in the balance sheet of a central bank also makes its balance sheet more sensitive to global interest rates and exposes it to the exchange rate risk.

The projected evolution of key macroeconomic variables – current account balance, capital and financial flows, external financial flows (capital and financial flows net of current account balance), and monetary base/reserve money in the BAU scenario—along with past data from 2017–2018 to 2022–2023 are presented in Table 8.

As India normally runs a CAD, we project it for each year up to 2030. The CAD is projected in the range of 1 per cent of GDP (US$41 billion) and 2.4 per cent of GDP (US$120 billion). India has also been receiving capital and financial flows, which are generally much more than its CAD and which, therefore, are managed (Mohan, 2006; Mohan, 2008). India's foreign exchange reserves were about 15.5 per cent of GDP in 2022–2023. It is reasonable to expect that India will continue to maintain at least the same level of foreign exchange reserves as in 2022–2023 as percentage of GDP, which have been reckoned for arriving at capital and financial inflows.[15] Considering this, external financial flows are estimated at US$530 billion during 2023-2030 ranging from US$58 billion to US$98 billion annually.

Table 8: Key Macro Economic Indicators: Projections - BAU Scenario

	Year	CAB[16]		Capital Inflows[17]		External Financial Flows		Expansion in Monetary Base	
		(billion US$)	(per cent of GDP)	(billion US$)	(per cent of GDP)	(billion US$)	(per cent of GDP)	(billion US$) *	(per cent of GDP)
	(1)	(2)	(3)	(4)	(5)	(6) = (2+4)	(7) = (3+5)	(8)	(9)
Actual	2016–2017	-38	-1.4	77	2.9	10	0.4	-	-
	2017–2018	-66	-2.4	60	2.2	55	2.0	80	2.9
	2018–2019	-30	-1.0	87	3.1	-12	-0.4	51	1.8
	2019–2020	33	1.2	71	2.7	65	2.4	34	1.3
	2020–2021	-33	-1.1	100	3.2	99	3.1	78	2.5
	2021–2022	-79	-2.3	51	1.5	30	0.9	62	1.8
	2022–2023	-32	-0.9	71	1.9	-29	-0.8	39	1.0
Projection	2023–2024	-41	-1.0	98	2.4	58	1.4	47	1.2
	2024–2025	-95	-2.1	158	3.5	63	1.4	60	1.3
	2025–2026	-120	-2.4	188	3.8	68	1.4	64	1.3
	2026–2027	-110	-2.0	184	3.4	74	1.4	68	1.3
	2027–2028	-100	-1.7	180	3.0	80	1.3	73	1.2
	2028–2029	-142	-2.2	231	3.5	89	1.4	78	1.2
	2029–2030	-120	-1.7	218	3.0	98	1.4	84	1.2
Average of Projections		-104	-1.9	180	3.2	76	1.4	68	1.2

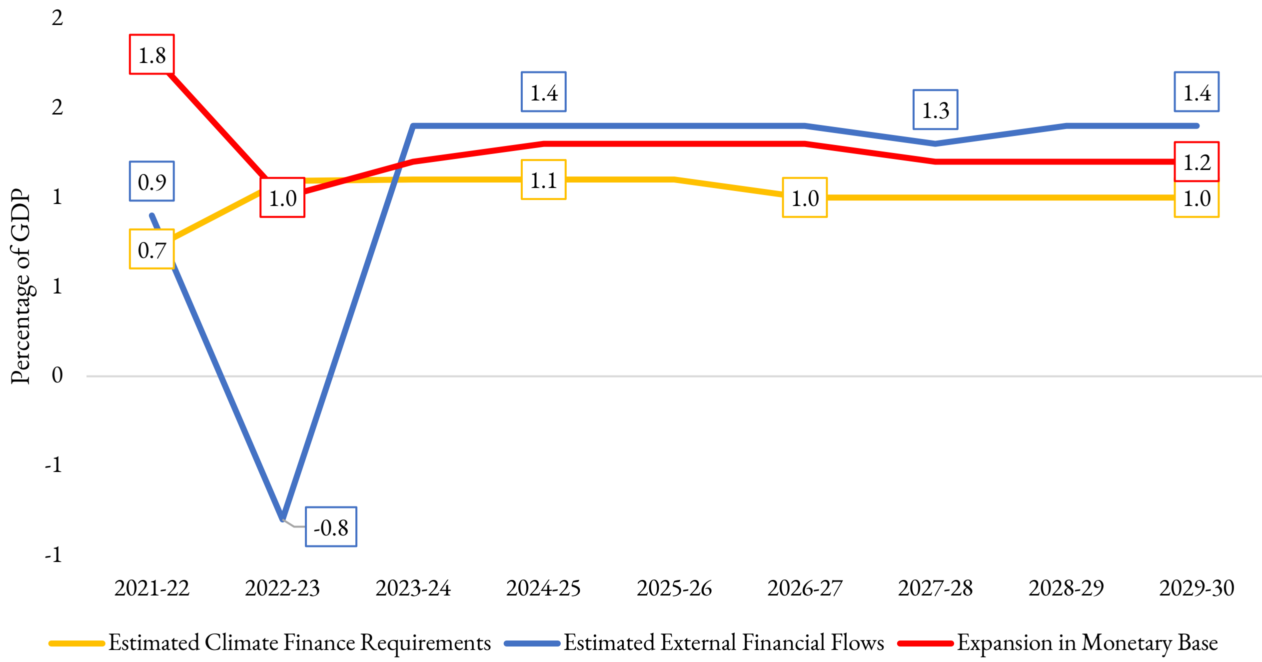
Notes: (i) This analysis was conducted before actual 2023-24 data became available. Therefore, 2023-24 figures are shown as projections, not actuals.
(ii) Figures of monetary base in Rupees were converted into US$ assuming that the local currency (rupee) depreciates by 3 per cent every year.
Source: RBI, World Economic Outlook, IMF, World Bank Statistics, and authors' calculations.

India's monetary base has been expanding broadly in line with the nominal GDP growth rate. Assuming a nominal GDP growth rate of 10.5 per cent, the annual accretions in India's monetary base range from US$47 billion to US$84 billion up to 2030, aggregating US$474 billion up to 2030.

It may be noted that external financial flows at US$530 billion up to 2030 are projected to be more than the projected expansion in monetary base.

On a yearly basis, the annual external financial flows in the BAU are projected to exceed the desired expansion in monetary base up to 2030. The annual climate finance requirement up to 2030 is estimated 1.0 -1.1 per cent up to 2030 (Figure 9)[18]. Thus, it would be a challenge to manage external financial flows in the BAU along with large climate financial flows, should they arise from external sources. Therefore, for absorbing climate finance flows from external sources, India may have to prudently widen the current account deficit (CAD) but not exceeding 2.5 per cent of GDP in view of prudential and financial stability concerns, depending on the availability of climate finance from external sources. The remaining gap would need to be financed from domestic sources by enhancing the saving rate, if resources are not to be weaned away from other productive sectors of the economy.

Figure 9: Monetary Base, External Financial Flows and Climate Finance Requirements



Source: Authors' calculations.

5.2 Climate Finance and External Financial Flows

It is not clear at this stage what proportion of the estimated climate finance requirements would be met from external sources. It is normally a challenge to manage capital and financial flows over and above the CAD. Therefore, it would be even a bigger challenge to manage large climate finance flows from external sources over and above the external financial flows in the BAU scenario.

The climate finance estimate of 1.3 per cent of GDP means that gross fixed capital formation as a percentage of GDP would need to rise to the same extent, if resources are not to be weaned away from other sectors. How can we then finance climate action in the power, road transport, steel and cement sectors? There would be a need for a combination of financial resources both from external and domestic sources.

The ability to absorb external financial flows can be enhanced by widening the current account deficit, while keeping it at a sustainable level. External financial flows, including climate finance flows from external sources, that exceed the expansion in the CAD would need to be managed skillfully. Alongside the expansion in the CAD, there will also be a need to step up the domestic saving rate commensurate with the remaining need for climate finance. If at least half of the required climate finance of 1.3 per cent of GDP is contributed by climate finance flows from external sources (by expanding the CAD), the expansion needed in the domestic saving rate falls within a feasible range. This will ensure that other productive sectors of the economy are not deprived of financial resources from the system.

6. Summing Up and Policy Implications

The escalating levels of CO_2 emissions globally raise serious concerns, with India's contribution rising to 8.2 per cent in 2023. India, as one of the fastest-growing emerging market economies, has been expanding infrastructure rapidly, contributing significantly to CO_2 emissions. Key factors driving this rise include the steel and cement sectors, the country's heavy reliance on coal for power production and the growing number of vehicles contributing to vehicular emissions.

These challenges underscore an urgent need for India to adopt and implement robust climate action plans. In response to its increasing emissions and vulnerability to climate change, India has been approaching the issue in a comprehensive and forward-looking manner, highlighted by its ambitious commitments and targets set out in NDCs under the Paris Agreement. India has not only been setting ambitious targets, but it has been achieving some of them well ahead of time. For instance, India reduced the emission intensity relative to GDP by 36 per cent between 2005 and 2020 against the initial target of 33-35 per cent by 2030 and achieved the target of 40 per cent of its installed power capacity through non-fossil fuel sources by 2023, as against the deadline of 2030.

The scale of financing required to meet the targets set in the NDCs by 2030 is large. Various estimates of climate finance requirements for India range from US$160 billion to US$288 billion annually up to 2030. The analysis in this paper estimates that the country will require significantly lower climate finance – US$467 billion (at current prices) from 2022–2030 – than suggested by existing estimates to address the climate financing needs of the four key sectors: power, road transport, steel, and cement. This translates to an annual requirement of US$54 billion or 1.3 per cent of India's GDP. The variation in estimates arises not only from differences in underlying assumptions, sectoral coverage and methodological approaches (such as top-down versus bottom-up), but also because, unlike the widely held belief, the decarbonisation of the power sector in India does not require large additional capital investment relative to what would have happened in a business-as-usual scenario. This is due to a collapse in the cost of renewable technologies in recent years. The cost per megawatt for setting up a solar power plant is now 50 per cent lower, and that of wind power plants is now almost one-third lower, than that of coal-based plants. This cost advantage makes renewables economically viable, reducing the overall investment needed for mitigating emissions in the power sector.

Of all sectors, the largest climate finance requirements (about one-half) are estimated for the steel sector at US$251 billion for 2022–2030. Though lower in absolute terms than that of China, India's climate finance requirement for the steel sector relative to GDP (0.7 per cent) is the highest among G20 emerging economies, highlighting the financial challenge of decarbonising India's steel sector (Raj & Mohan, 2024). This is followed by the cement sector, with climate finance requirement estimated at US$141 billion. Several factors drive India's large climate finance requirements for the steel and cement sectors. First, crude steel production is officially projected to almost double by 2030, while India's cement production is projected to rise by 82 per cent to reach 674 million tonnes by 2030 (18 per cent of global output, up from 9 per cent in 2022). Second, there is limited scope to abate CO_2 from these two sectors through energy efficiency, the use of renewable sources of energy and alternative fuels, and the reduction in the clinker factor (for cement). Therefore, the decarbonisation of these two sectors would require the use of carbon capture and storage technology, which is expensive to deploy but the only feasible option at this stage. Hydrogen-based steel manufacturing and alternative cement formulations are being explored, but they are not yet commercially viable at scale (IEA, 2021). For developing green hydrogen, there are both production process and economic challenges at the global level, let alone for India.

Climate finance for the road sector is required for the electrification of the vehicle fleet (from ICEVs to EVs) and to build the charging infrastructure. The country is estimated to require an additional capex of US$10 billion for switching from ICEVs to EVs. This apart, about US$8 billion is required for developing the charging infrastructure for EVs.

India is estimated to require an additional capex of US$47 billion for the power sector during 2024–2030 to transition from fossil fuel-based sources of power generation to renewables. However, after reckoning for storage costs, the total climate finance requirement for the power sector is estimated at US$57 billion.

The decarbonisation of the four sectors considered in this study is expected to reduce the use of a large amount of fossil fuels—291 MT of coal (152 MT in the power sector, 85 MT in the cement sector and 54 MT in the steel sector) and 72 billion litres of petrol and diesel, which would help mitigate about 6.9 billion tonnes of CO_2 emissions (excluding road transport). The average cost of mitigating CO_2 emissions in the three sectors (power, steel, and cement)[12] works out to be US$61 per tonne of CO_2. The per-unit cost of abating CO_2 is the largest for the cement sector (US$70 per tonne of CO_2), followed by steel (US$69).

It is uncertain at this stage how much of India's climate finance requirements would be met through external official multilateral/bilateral sources. Irrespective of the scale, however, a macro-consistency analysis suggests that India would need to manage climate finance flows from external sources skilfully. External financial flows (current account balance plus capital and financial inflows) for India are projected in the range of 1.3–1.4 per cent of GDP (US$58–98 billion) during 2023–2030 in the business-as-usual scenario. As it is, large capital and financial flows over the CAD in the BAU scenario pose a challenge. Therefore, large climate finance flows from external sources over and above the external financial flows in the BAU scenario could pose an even bigger challenge and would need to be managed deftly. However, should India widen its CAD, it should be able to absorb larger capital flows, including climate finance. In this context, it is significant that CCS technology is not available domestically and may have to be imported. India's current account deficit in 2024–2025 was 1.1 per cent of GDP but averaged about 1.7 per cent of GDP in the past 20 years. On an average, it is projected to be 1.9 per cent of GDP up to 2030. Therefore, India may have to prudently widen the CAD, subject to a maximum limit of 2.5 per cent of GDP, depending on the availability of climate finance from external sources.

The current account deficit up to 2.5 per cent of GDP could still be considered sustainable, especially if India receives large climate finance flows from external sources. The remaining gap would need to be financed from domestic sources by improving the saving rate.

In this context, it is also important to note that (i) the steel and cement sectors are predominantly in the private sector; (ii) road transport is owned and operated largely by the private sector; and (iii) there is a mix of private and public sector involvement in the power sector, with a large segment in the public sector. As such, the main role of the government will be to provide subsidies and incentives to promote the low-carbon economy. Nevertheless, the bulk of the resources would need to be mobilised from the private sector by stepping up the saving rate to ensure that resources are not weaned away from other sectors into environment-related projects. It is significant that to the extent the general government reduces its fiscal deficit, it frees up resources for the private sector.

The need for climate finance has arisen at a time when India is stepping up its efforts to accelerate its growth rate by focusing on physical infrastructure development and promoting manufacturing. It is only then that India can catch up with its peers in terms of per capita income and simultaneously make a significant dent in poverty. Therefore, India would need to manage its available resources skilfully by balancing competing uses. India's savings rate has declined in the recent period. Therefore, the key focus of policymaking needs to be on improving the savings rate - of the general government (by reducing dissaving) and the household sector. This would help India navigate the challenges of pursuing development goals and achieving the country's environmental and sustainability targets without complicating macroeconomic management.

It is important to recognise certain limitations of this study.

First, this study adopts a sectoral approach to estimate the additional capital needs for only four sectors: power, transport, steel and cement. Consequently, the estimates in this study should not be construed as the climate finance requirements for the whole economy.

Second, climate finance estimates are based on the official projections up to 2030. Should actual numbers deviate from projected numbers or projections are revised significantly upward or downward, they would impinge on estimates made in this study.

Third, the estimates arrived at in this study are based on current technologies that are available in the market. Should newer and affordable technologies become available, going forward, they could have a significant bearing on the climate finance estimates made in this study.

Fourth, this study focuses solely on capital needs for mitigation efforts, excluding investments necessary for adaptation efforts.

Fifth, for estimating costs for the steel and cement sectors, the study used only the global average for CCS costs as the relevant data in the case of India were not available.

Sixth, CCS estimates have been worked out in steel and cement from 2022 to 2030. Actual capital expenditure could turn out to be lower than estimated if CCS facility is installed before 2030 as it may not be feasible to install CCS facility for small incremental capacity of cement and steel production added subsequently up to 2030.

Seventh, all climate finance estimates are purely based on capital expenditure and not operational costs.

Eighth, carbon capture also has some uses. However, most of such uses at this stage entail even larger costs than storage. The uses of carbon capture, therefore, have not been considered in this study.

However, should the cost of such uses decline drastically to fall below the cost of storage in the future due to technological advances, it may be more appropriate to make such uses of carbon that would be captured than storage, thereby reducing the estimates arrived for the steel and cement sectors in this study. Finally, the projections of external financial flows based on historical data may not fully capture the evolving dynamics in trade and capital flows in case there are structural changes, going forward

References

Acharya, M. (2024, June 20). *How to apply for EV charging station in India? Cost, franchise, government guidelines*.

Adams, C., Ferrarini, B., Park, D., Asian Development Bank, Cynthia Petalcorin, Christian Mina, & Lagrimas E. Cuevas. (2010). *Fiscal sustainability in developing Asia*. https://www.adb.org/sites/default/files/publication/28414/economics-wp205.pdf

Aggarwal, M. (2024, May). Kiln electrification key to decarbonisation of manufacturing in cement industry. Down to Earth. Retrieved from https://www.downtoearth.org.in/blog/climate-change/kiln-electrification-key-to-decarbonisation-of-manufacturing-in-cement-industry-95915

Analyzing and Managing Fiscal Risks – Best practices. (2016). *IMF Policy Paper*, *16*(25). https://doi.org/10.5089/9781498345668.007

Andrew, R. M. (2018). "Global CO_2 emissions from cement production." *Environmental Science & Technology*, 52(10), 6139-6147. Retrieved from pubs.acs.org

Bhattacharya, A., Songwe, V., Soubeyran, E., & Stern, N. (2023). *A climate finance framework: Decisive action to deliver on the Paris Agreement – Summary.* London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science.

Biswas, T., Yadav, D., and Guhan, A. (2020) A Green Hydrogen Economy for India: Policy and Technology Imperatives to Lower Production Cost. *New Delhi: Council on Energy, Environment and Water.*

Bloomberg. (2022, October 18). Global Carbon Capture Capacity Due to Rise Sixfold by 2030. Retrieved from: https://about.bnef.com/blog/global-carbon-capture-capacity-due-to-rise-sixfold-by-2030/#_ftn1

Bohn, H. (1998). The behaviour of U.S. public debt and deficits on JSTOR. *The Quarterly Journal of Economics*, *113*(3), 949–963. http://www.jstor.org/stable/2586878

Cars24. (2024, April). What is the Cost of Setting Up an Electric Car Charging Station in India? *Electric Cars and Hybrids*. https://www.cars24.com/blog/cost-electric-car-charging-station-india/

Cembureau (n.d.). Our 2050 Roadmap: The 5C Approach. Retrieved from https://lowcarboneconomy.cembureau.eu/carbon-neutrality/our-2050-roadmap-the-5c-approach-clinker/

CEMBUREAU. (2022). *Activity Report.* https://cembureau.eu/media/m3jcyfre/cembureau-activity-report-2022-light.pdf

Cement Manufacturers Association, 2021. *Making every drop count – A Water Positive Industry.* (December 31, 2021) https://www.cmaindia.org/making-every-drop-count.

Chowdhury, M. M. I., Rahman, S. M., Amran, M. I. U. A., Malik, K., Abubakar, I. R., Aina, Y. A., ... & Hasan, M. A. (2022). Climate change impacts on food system security and sustainability in Bangladesh. *Research Square.* https://doi.org/10.21203/rs.3.rs-1673139/v1

Climate Policy Initiative, & Tiwari, S. (2021). *Transforming India's climate finance through sector-specific financial institutions.* https://www.climatepolicyinitiative.org/transforming-indias-climate-finance-through-sector-specific-financial-institutions/#:~:text=Climate%20finance%20needs

Climate Policy Initiative, Jena, L. P., & Purkayastha, D. (2024, June 27). *Accelerating Green Finance in India: Definitions and Beyond.* CPI. https://www.climatepolicyinitiative.org/publication/accelerating-green-finance-in-india-definitions-and-beyond/

Climate Policy Initiative, Sinha, J., Jain, S., Padmanabhi, R., & Acharya, M. (2020). *Landscape of Green Finance in India.* https://www.climatepolicyinitiative.org/wp-content/uploads/2020/09/Landscape-of-Green-Finance-in-India-1-2.pdf

Costs and benefits of energy transition. Energypedia. Retrieved from https://energypedia.info/wiki/Costs_and_benefits_of_energy_transition

Department of Economic Affairs, Government of India. (2017). *FRBM Review Committee Report Vol-I.* https://dea.gov.in/sites/default/files/Volume%201%20FRBM%20Review%20Committee%20Report.pdf

Elango, S., Nitturu, K., Yadav, D., Sripathy, P., Patidar, R., & Mallya, H. (2023). Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water.

Elango, S., Nitturu, K., Yadav, D., Sripathy, P., Patidar, R., & Mallya, H. (2023). Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water.

Evans, M. (2021, September 28). Carbon capture and storage: how far can costs fall? Retrieved from: https://www.woodmac.com/news/opinion/carbon-capture-and-storage-how-far-can-costs-fall/

Fischer, G., Shah, M., Tubiello, F. N., & Van Velhuizen, H. (2005). Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. *Philosophical Transactions - Royal Society. Biological Sciences, 360*(1463), 2067–2083. https://doi.org/10.1098/rstb.2005.1744

Garg, V., Gulia, J.,Gupta, K., Shaik, N., & Srivastava, S. (2023, September 14). Steel decarbonisation in India. Institute for Energy Economics and Financial Analysis. Retrieved from: https://ieefa.org/sites/default/files/2023-09/Steel%20Decarbonisation%20in%20India_September%202023_2.pdf.

Global Carbon Budget. (2023). – with major processing by Our World in Data. "Annual CO_2 emissions from cement – GCB" [dataset]. Global Carbon Project, "Global Carbon Budget". Retrieved from: https://ourworldindata.org/grapher/annual-co2-cement.

Global Carbon Budget. (2023). *Annual CO_2 emissions from cement – GCB* [Dataset]. Our World in Data. https://ourworldindata.org/grapher/annual-co2-cement

Global CCS Institute (2023). *The Status of CCS: Policy and Investment Trends.* Retrieved from globalccsinstitute.com

Government of India, Ministry of Power, & Central Electricity Authority. (2023). *Report on Optimal Generation Capacity Mix for 2029-30 Version 2.0* [Report]. https://cea.nic.in/wp-content/uploads/irp/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf

Government of India. (2022). India's updated first nationally determined contribution under Paris Agreement (2021-2030). In *Submission to UNFCCC* (pp. 1–3). https://unfccc.int/sites/default/files/NDC/2022-08/India%20Updated%20First%20Nationally%20Determined%20Contrib.pdf

Gupta, S., Bhandari, L., Jakhu, R., Sharma, M., & Centre for Social and Economic Progress. (2022). Climate Change, Weather Anomalies, and Agriculture: Impact on Output of Major Crops in India. *CSEP Working Paper Series.* https://csep.org/wp-content/uploads/2022/12/Climate-Change-impact_web.pdf

Hasanbeigi, A. (2022, April 7). Cleanest and Dirtiest Countries for Secondary (EAF) Steel Production. *Global Efficiency Intelligence.* Retrieved from: https://www.globalefficiencyintel.com/new-blog/2020/9/2/part-2-cleanest-and-dirtiest-countries-for-secondary-eaf-steel-production.

Hasanbeigi, A., and Bhadbhade, N. (June 2023). Emissions Impacts of Alternative Fuels Combustion in the Cement Industry. Global Efficiency Intelligence. Florida, United States.

Ians. (2024, January 7). View: Time for India to move into top gear with an eye on 2030 EV public infra goal. *The Economic Times.* https://economictimes.indiatimes.com/industry/renewables/time-for-india-to-move-into-top-gear-with-an-eye-on-2030-ev-public-infra-goal/articleshow/106608886.cms?from=mdr

IEA (2019), The Future of Hydrogen, IEA, Paris https://www.iea.org/reports/the-future-of-hydrogen.

IEA (2021a). Is carbon capture too expensive? IEA, Paris. Retrieved from: https://www.iea.org/commentaries/is-carbon-capture-too-expensive

IEA (2021a). Is carbon capture too expensive?, IEA, Paris. Retrieved from: https://www.iea.org/commentaries/is-carbon-capture-too-expensive.

IEA (2023). World Energy Outlook. Retrieved from https://iea.blob.core.windows.net/assets/86ede39e-4436-42d7-ba2a-edf61467e070/WorldEnergyOutlook2023.pdf

IEA (2024). *Batteries and Secure Energy Transitions*. Retrieved from https://iea.blob.core.windows.net/assets/cb39c1bf-d2b3-446d-8c35-aae6b1f3a4a0/BatteriesandSecureEnergyTransitions.pdf

IMF (2021). *Reaching Net zero Emissions*. Washington D.C. International Monetary Fund. Retrieved from https://outlook.office.com/mail/inbox/id/AAQkADBmMjFlY2M4LTJmNzItNGVmNS1hYmFkLTNjNDZlYjdjN2Q1NAAQAAYuYk5q%2BqNHpFn8pCHf2PI%3D

India's clean energy transition is rapidly underway, benefiting the entire world – Analysis - IEA. (2022, January 10). IEA. https://iea.org/commentaries/india-s-clean-energy-transition-is-rapidly-underway-benefiting-the-entire-world

International Energy Agency (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector*. Retrieved from iea.org

International Energy Agency (2021). *The Role of Hydrogen in Decarbonizing Heavy Industry*. Retrieved from iea.org

International Energy Agency. (2021). *Carbon Capture, Utilisation, and Storage (CCUS) in Industry*. Retrieved from iea.org

IPCC (2022). *Carbon Capture and Storage: Risks and Mitigation Strategies*. Retrieved from ipcc.ch

IPCC (2022). Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the IPCC Sixth Assessment Report. Retrieved from: https://www.ipcc.ch/report/ar6/wg3/

Kaur, B., Mukherjee, A., & Ekka, A. P. (2018). Debt sustainability of states in India: An assessment. *Indian Economic Review/Indian Economic Review*, *53*(1–2), 93–129. https://doi.org/10.1007/s41775-018-0018-y

Kumar P. (2024, May 30). Electric arc furnace-based steel production is witnessing a global rise. Down to Earth. Retrieved from: https://www.downtoearth.org.in/blog/energy/electric-arc-furnace-based-steel-production-is-witnessing-a-global-rise-96421.

Lebling, K., Gangotra, A., Hausker, K., & Byrum, Z. (2023, November 13). 7 Things to Know About Carbon Capture, Utilization and Sequestration. Retrieved from: https://www.wri.org/insights/carbon-capture-technology.

London School of Economics and Political Science, Grantham Research Institute on Climate Change and the Environment. (2023, March 13). What is carbon capture, usage and storage (CCUS) and what role can it play in tackling climate change? Retrieved from https://www.lse.ac.uk/granthaminstitute/explainers/what-is-carbon-capture-and-storage-and-what-role-can-it-play-in-tackling-climate-change/#:~:text=CCUS%20offers%20the%20most%20cost.

McCollum, D. L., Zhou, W., Bertram, C., De Boer, H., Bosetti, V., Busch, S., Després, J., Drouet, L., Emmerling, J., Fay, M., Fricko, O., Fujimori, S., Gidden, M., Harmsen, M., Huppmann, D., Iyer, G., Krey, V., Kriegler, E., Nicolas, C., Riahi, K. (2018). Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. *Nature Energy*, *3*(7), 589–599. https://doi.org/10.1038/s41560-018-0179-z

Meyfroidt, P. (2018). Trade-offs between environment and livelihoods: Bridging the global land use and food security discussions. *Global Food Security*, *16*, 9–16. https://doi.org/10.1016/j.gfs.2017.08.001

Miller, S., Bellamy, R., & Markusson, N. (2020). Public perception of CCS: A review of global case studies. Energy Policy, 140, 111385.

Ministry of Environment, Forest and Climate Change. (2015). *India's Intended Nationally Determined Contribution is Balanced and Comprehensive: Environment Minister*. https://pib.gov.in/newsite/PrintRelease.aspx?relid=128403

Ministry of Finance. (2012). *UNION BUDGET & ECONOMIC SURVEY*. https://www.indiabudget.gov.in/budget2012-2013/survey.asp

Ministry of Heavy Industries, Government of India. (2023, March). *6,586 operational Public EV Charging Stations in India*. https://pib.gov.in/PressReleasePage.aspx?PRID=1910392

Ministry of Power (Government of India). *National Electricity Policy*. Retrieved from https://powermin.gov.in/en/content/national-electricity-policy

Ministry of Steel, Government of India (GoI). *Make in India*. Retrieved from: https://steel.gov.in/en/make-india

Ministry of Steel, Government of India. (2024) *Greening the steel sector in India: Roadmap and action plan*. Neha Verma, Deepak Yadav, Karthik Shetty, Rudhi Pradhan, Karan Kothadiya, Rishabh Patidar, Hemant Mallya, Sobhanbabu PRK, Dr. N K Ram, Souvik Bhattacharjya, Manish Kumar Shrivastava, Arupendra Nath Mullick, Mayank Aggarwal, Mandavi Singh.

Mohan, R. (2008). **Capital flows to India**, BIS Papers chapters, in: Bank for International Settlements (ed.), Financial globalisation and emerging market capital flows, volume 44, pages 235-263, Bank for International Settlements.

Mohan, R. Reserve Bank of India. (2006, May). *Monetary Policy and Exchange Rate Frameworks: The Indian Experience*. Second High-Level Seminar on Asian Financial Integration, Singapore. https://www.rbi.org.in/Scripts/BS_SpeechesView.aspx?Id=288

NASA Earth Observatory. (n.d.). *World of Change: Global temperatures*. https://earthobservatory.nasa.gov/world-of-change/global-temperatures#:~:text=According%20per%20cent20to%20per%20cent20an%20per%20cent20ongoing%20per%20cent20temperature,1.9%20per%20centC2%20per%20centB0%20per%20cent20Fahrenheit)%20per%20cent20since%20per%20cent201880

Nirula, A (2019). *India's Power Distribution Sector: An assessment of financial and operational sustainability*. New Delhi: Brookings India. Retrieved from https://www.brookings.edu/wp-content/uploads/2019/10/India's-Power-Distribution-Sector.pdf

NITI Aayog. (2014). *The Final Report of the Expert Group on Low Carbon Strategies for Inclusive Growth*. https://cstep.in/drupal/sites/default/files/2019-01/CSTEP_RR_Low_Carbon_Strategies_for_Inclusive_Growth_final_report_2014.pdf

NITI Aayog. (2022, November). Carbon Capture, Utilisation, and Storage (CCUS) Policy Framework and its Deployment Mechanism in India.

Nitturu, K., Sripathy, P., Yadav, D., Patidar, R., & Mallya, H. (2023). Evaluating Net-zero for the Indian Cement Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water.

Nitturu, K., Sripathy, P., Yadav, D., Patidar, R., & Mallya, H. (2023). Evaluating Net-zero for the Indian Cement Industry: Marginal Abatement Cost Curves of Carbon Mitigation Technologies. New Delhi: Council on Energy, Environment and Water.

Pickson, R. B., & Boateng, E. (2021). Climate change: a friend or foe to food security in Africa? *Environment, Development and Sustainability*, *24*(3), 4387–4412. https://doi.org/10.1007/s10668-021-01621-8

Potsdam Institute for Climate Impact Research. (2024). *38 trillion dollars in damages each year: World economy already committed to income reduction of 19% due to climate change.* Retrieved June 28, 2024, from https://www.pik-potsdam.de/en/news/latest-news/38-trillion-dollars-in-damages-each-year-world-economy-already-committed-to-income-reduction-of-19-due-to-climate-change

PRS Legislative Research (2022). *Power Distribution Sector*. New Delhi: Institute for Policy Research Studies. Retrieved from https://prsindia.org/files/bills_acts/bills_parliament/2022/Discussion_Paper_Power_Distribution_Sector.pdf

Qiao, Y., Liu, W., Guo, R., Sun, S., Zhang, S., Bailey, J. J. & Wu, C. (2023). Techno-economic analysis of integrated carbon capture and utilisation compared with carbon capture and utilisation with syngas production. Fuel, 332, 125972.

Raj, J., Mohan, R., (2024). An Assessment of Climate Finance - Nine Major Economies; Centre for Social and Economic Progress. *(forthcoming).*

Raj, J., Pattanaik, S., Bhattacharya, I. (2018, August). *Forex Market Operations and Liquidity Management*. Reserve Bank of India. https://m.rbi.org.in/Scripts/BS_ViewBulletin.aspx?Id=17703

Raj, J., Shakya, V., & Bhapta, K. (2024, June 3). Mobilising climate finance: Imperative of carbon pricing. *Financial Express*. https://www.financialexpress.com/opinion/mobilising-climate-finance-imperative-of-carbon-pricing/3511704/

Reserve Bank of India (2023). *Report on Currency and Finance*. https://rbi.org.in/Scripts/AnnualPublications.aspx?head=Report%20on%20Currency%20and%20Finance

Reserve Bank of India. (2003). *Report of the Working Group on Instruments of Sterilisation*. https://www.rbi.org.in/scripts/PublicationReportDetails.aspx?ID=343

Reserve Bank of India. (2020). *State Finances: A Risk Analysis*.

Reserve Bank of India. (2022). *State Finances: A Risk Analysis*.

Rubin, E. S., Davison, J. E., & Herzog, H. J. (2012). "The cost of CO_2 capture and storage." *ScienceDirect*. Retrieved from sciencedirect.com

Singh, V. P., Sidhu, G., Centre for Energy Finance, CEEW-CEF, Dutt, A., UNCCC UK, UNEP, GFANZ, Chaturvedi, V., & Malyan, A. (2021). Investment sizing India's 2070 Net-Zero target. In *Issue Brief*. https://www.ceew.in/cef/solutions-factory/publications/CEEW-CEF-Investment-Sizing-India%E2%80%99s-2070-Net-Zero-Target.pdf

Smith, E., Morris, J., Kheshgi, H., Teletzke, G., Herzog, H., & Paltsev, S. (2021). The cost of CO2 transport and storage in global integrated assessment modelling. International Journal of Greenhouse Gas Control, 109.

South African Iron and Steel Institute. (n.d). Steel is Green. Retrieved from https://www.saisi.org/steel-is-green/

Srinivasan, M., Ghoge, K., Haldar, S., Bazaz, A., Revi, A., & Indian Institute for Human Settlements. (2023). *Climate finance in India 2023* (IIHS Communications and Design & IIHS Word Lab, Eds.). https://iihs.co.in/knowledge-gateway/wp-content/uploads/2023/11/20231128_Climate-Finance-in-India2023.pdf

The World Bank. (2022). *Climate investment opportunities in India's cooling sector*. International Bank for Reconstruction and Development / The World Bank. https://documents1.worldbank.org/curated/en/099920011222212474/pdf/P15743300f4cc10380b9f6051f8e7ed1147.pdf

Tiwari, A. K. (2012). Debt Sustainability in India: Empirical Evidence Estimating Time-7. Varying Parameters. *Economics Bulletin*, *32*(2), 1133–1141. https://EconPapers.repec.org/RePEc:ebl:ecbull:eb-11-00871

U.S. Government Accountability Office. (2022). *Carbon Capture and Storage: Status and Key Challenges*. Retrieved from gao.gov

US EPA. (2024, February 28). *Basic information about coral reefs*. https://www.epa.gov/coral-reefs/basic-information-about-coral-reefs#:~:text=An%20per%20cent20estimated%20per%20cent2025%20per%20cent20per%20cent%20of%20species

Vishwanathan, S. S., & Garg, A. (2020). Energy system transformation to meet NDC, 2 °C, and well below 2 °C targets for India. *Climatic Change*, *162*(4), 1877–1891. https://doi.org/10.1007/s10584-019-02616-1

Will India get too hot to work? (2020). In *McKinsey Global Institute*. https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/will%20india%20get%20too%20hot%20to%20work/will-india-get%20too-hot-to-work-vf.pdf

World Steel Association. (2023). World Steel in Figures 2023. Retrieved from: https://worldsteel.org/data/world-steel-in-figures-2023/#crude-steel-production-by-process-2022.

World Steel Association. (n.d). World Wide Cement Production 2018 & Forecast 2030. Retrieved from: https://www.worldcementassociation.org/images/info-graphics/001-World-Wide-Cement-Production.pdf.

Zhou, W., McCollum, D. L., Fricko, O., Fujimori, S., Gidden, M., Guo, F., Hasegawa, T., Huang, H., Huppmann, D., Krey, V., Liu, C., Parkinson, S., Riahi, K., Rafaj, P., Schoepp, W., Yang, F., & Zhou, Y. (2020). Decarbonization pathways and energy investment needs for developing Asia in line with 'well below' 2°C. *Climate Policy*, *20*(2), 234–245. https://doi.org/10.1080/14693062.2020.1722606

Appendix

Appendix 1: Climate Finance Requirements—Power Sector

Table A1.1: Climate Finance Requirements - Power Sector

		Installed Capacity (GW)			Total Electricity Generation (TWH) [19]		Capex (US$ Billion)			
Source	PLF (%)	2023 (Actual)	Government Projection - 2030	BAU scenario - 2030	Government Projection - 2030	BAU scenario - 2030	Capital Cost- (US$ Million Per MW of Installed Capacity)	Based on Government Projection - 2024 - 2030	Based on BAU Scenario - 2024 - 2030	Additional Capital Expenditure - 2024–2030
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(11)	(12)	(13) = (11-12)
1. Fossil-based	-	**237**	**277**	**321**	**1,428**	**1,660**	-	**39**	**82**	**-43**
Coal-based	63.7	212	252	292	1,404	1,632	0.99	39	80	-40
Gas-based	10.8	25	25	29	24	27	0.6	0	2	-2
2.Non-fossil-based	-	**169**	**476**	**358**	**935**	**703**	-	**221**	**131**	**90**
Hydro	39.5	42	54	41	186	140	1.08	13	-2	14
Solar PV	17.4	67	293	220	447	336	0.62	140	95	45
Wind	19.6	43	100	75	172	129	0.91	52	30	23
Biomass	19.6	11	15	11	25	19	0.66	2	0	2
Nuclear	77.2	7	15	12	105	79	1.53	13	7	6
3. Total (1+2)	-	**406**	**753**	**679**	**2,363**	**2,363**	-	**260**	**213**	**47**
4. Storage	-	**4.82**	**61**	**46**	-	-	-	**33**	**23**	**10**
Battery Storage	-	0.04	42	32	-	-	0.68	**22**	**16**	6
Pumped Storage	-	4.78	19	14	-	-	0.78	**11**	**7**	4
Grand Total (3+4)	-	-	-	-	**2,363**	**2,363**	-	-	-	**57**

PLF- Plant Load Factor; TWH—Terra Watt Hours

Source: CEA, Niti Aayog and authors' calculations.

Appendix 2: CCS Capex Estimates for the Power Sector

For estimating the CCS capex for the power sector, we need the per unit cost of CCS. Since it was not available for India, it was sourced from the global averages provided by the International Energy Agency (IEA, 2021). The levelized global average per-unit cost for CCS in the power sector is US$75 per tonne of CO_2. This CCS cost lacked transport and storage costs, which were obtained from Smith *et al.,* 2021. To arrive at the initial capex per unit of CCS, the methodology followed in Box 7 was used for the power sector as well.

The capex required to abate one unit of CO_2 via CCS was estimated at US$515. The CCS capex is assumed to be the same for both coal- and gas-based power plants. The total capex required to decarbonise the power sector through CCS was estimated at US$725 billion from 2024 to 2030 (Table A2.1).

Table A2.1: Capex estimates for CCS in the Power Sector

	Coal-based Power Plants			Gas-based Power Plants				
Year	**Installed Capacity**	**Electricity Generated**	**Total Emissions**	**Installed Capacity**	**Electricity Generated**	**Total Emissions**	**Per unit cost of CCS**	**Total Required Capex**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(11)
Unit	GW	TWH	Million Tonnes	GW	TWH[1]	Million Tonnes	US$ per tonne of CO_2	US$ Billion
2024	217	1,293	1,203	25	26	15	515	627 (8)
2025	6	33	30	0	0	0	515	15
2026	5	33	31	0	0	0	515	16
2027	6	34	31	0	0	0	515	16
2028	6	34	32	0	0	0	515	17
2029	6	36	33	0	0	0	515	17
2030	6	36	34	0	0	0	515	17
Total (2024-2030)	252	1499	1394	25	26	15		725 (8)

Note: Figures within parentheses in col 9 represent CCS capex required for gas-based plants.

Source: CEA, Niti Aayog and authors' calculations.

Appendix 3: Climate Finance Requirements—Road Transport Sector

Table A3.1: Climate Finance Requirements—Road Transport Sector

(Vehicles in ‘000; Amount in billion US$)

Vehicle Category	Vehicle type	Per unit Capital Cost (US$)	Vehicles Sold in 2022	Projected Sales-2030	BAU Sales-2030	Additional Capital Expenditure-2030	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	
ICE	2W	904	15,862	17,250	18,379	-1	
	3W	2,879	489	385	410	0	
	Cars & Taxis	8,761	2,970	4,950	5,274	-3	
	Bus	1,08,320	31	163	173	-1	
	Truck/Goods Vehicles	29,990	962	1,555	1,657	-3	
	TOTAL		**20,314**	**24,303**	**25,894**	**-8**	
EV	2W	1,046	728	10,500	9,163	1	
	3W	4,404	402	870	759	0	
	Cars & Taxis	13,573	48	670	585	1	
	Bus	2,09,933	2	13	11	0	
	Truck/Goods Vehicles	1,31,958	21	439	383	7	
	TOTAL		**1,200**	**12,492**	**10,901**	**11**	
A. Total (ICE+EV)	-		**21,515**	**36,794**	**36,794**	**3**	
B. Capex for Charging Infrastructure	Refer Appendix 4 for details						4
Grand Total (A + B)							7

Note: ICE- Internal combustion engine vehicles; EV: Electric Vehicles

Source: NITI Aayog, Bain and Company and authors’ calculations.

Appendix 4: Additional Capital Expenditure for the Charging Infrastructure

Table A4.1: Additional Capital Expenditure for the Charging Infrastructure

Charging Infrastructure	Per unit Capital Cost (US$)	Number of charging stations - 2022	Number of charging stations based on projections - 2030	Number of charging stations in the BAU scenario - 2030	Capex based on projected Charging Station - 2023-2030	Capex based on Charging Station in BAU Scenario - 2023 -2030	Additional Capital Expenditure - 2023 - 2030	Additional Capital Expenditure - 2030
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) = (6-7)	(9)
Charging Infrastructure	47,985	5,254	13,20,000	11,51,876	**62.8**	**54.8**	**8**	**4**

Source: NITI Aayog and Authors’ calculations.

Appendix 5: Data Sources - Steel and Cement Sectors

Table A5.1: Data Sources

Variable	Year	Cement	Steel
Production Volume	2022	Cembureau	Net Zero Industry
CO_2 Emissions	2022	Our World in Data	Net Zero Industry
Cost of carbon capture storage technology	Various Years	Global CCS Institute, IEA	Global CCS Institute, IEA
Production Projection	2030	World Cement Association,	Net Zero Industry

Notes

[1] We gratefully acknowledge the valuable research inputs provided by Aashi Gupta, Amshika Amar, Indramani Tiwari, Subhanshi Negi, and Priti Dubey. Without their hard work, this study would not have been possible. We would also like to express our sincere thanks to Montek Singh Ahluwalia, Laveesh Bhandari, Vinod Thomas, Sumant Sinha, Rishikesh Ram Bhandary, Rahul Tongia, Hemant Mallya, Deepak Yadav, Rajasekhar Devaguptapu, Sabarish Elango, Sharath Rao, Udit Mathur, and Utkarsh Patel for their useful comments on earlier versions of this paper.

[2] The period covered is 2022–2030 for the steel and cement sectors, 2024–2030 for the power sector, and 2023–30 for road transport.

[3] The period covered is 2022-2030 for the steel and cement sectors, 2024-2030 for the power sector, and 2023-2030 for road transport.

[4] Excluding hybrid vehicles.

[5] It is assumed that the entire expansion in the monetary base takes place through accretion in net foreign assets in the balance sheet of the Reserve Bank of India.

[6] It is a think tank set up by the Government of India.

[7] Since data on capex for the road transport sector were not readily available, the per unit sale price of a vehicle was proxied as its per unit capital expenditure.

[8] For our analysis, we have considered only coal and gas-based power plants, which constitute 97 per cent of India's installed thermal power capacity and 58 per cent of the total installed capacity in the power sector.

[9] The cost of renewable sources was deemed to be excessive even as late as 2014. That their costs would become competitive could not be foreseen at that time.

[10] The period is 2022–2030 for the steel and cement sectors, 2024–2030 for the power sector, and 2023–2030 for road transport.

[11] The integration cost has not been considered.

[12] The road transport sector could not be covered as the relevant data were not readily available.

[13] India targets the overnight interest rate in the call money market. In economies where central banks target interest rate, the factors affecting the monetary base are exogenous for the central bank. As such, those central banks may not exert direct influence on the size of the monetary base, which depends on the portfolio decisions of the private sector. Nevertheless, monetary base remains relevant as its unbridled growth may have a significant bearing on nominal interest rates and the macroeconomy.

[14] Under the MSS, the Government of India issued securities, but the proceeds raised therefrom were parked with the Reserve Bank of India. Thus, the government paid interest on securities issued under MSS but did not utilise the proceeds thereof.

[15] Capital flows thus arrived at broadly match with those projected by the IMF.

[16] Projected using the historical 10-year average of exports-to-world GDP and imports-to-domestic GDP ratios (excluding COVID-19 years 2020–2021 and 2021–2022), applied to IMF's GDP forecasts up to 2030. Exports and imports include goods, services, and primary and secondary income flows.

[17] Capital and financial flows and CAB are all reflected in changes in foreign exchange reserves, as indicated by:

$$\Delta Foreign\ Exchange\ Reserves_t = Current\ Account\ Balance_t + Capital\ Inflows_t + Financial\ Inflows_t$$

[18] Given the large initial capital expenditure requirement estimated for 2022–$140 billion for the steel sector and $78 billion for the cement sector—it is assumed that the initial estimated capital expenditure would be evenly distributed in the remaining years up to 2030. This results in an annual capex of $15.6 billion per year for the steel sector and $8.7 billion for the cement sector, which is added to capex required for mitigating incremental carbon emissions every year.

[19] Plant load factor of fossil fuel-based sources of power is much larger than that based on renewables (other than nuclear-based sources). Therefore, the installed capacity in fossil fuel-based sources of power in 2030 was adjusted to match the power generated based on the projected installed capacity made by the government for 2030.