WRI INDIA

EXPERT NOTE

Pathways to Net Zero: Policies and Measures for Industrial Decarbonization in India

TRANSFORMING INDIAN INDUSTRY FOR A SUSTAINABLE FUTURE

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INTRODUCTION

The need for an early and concerted effort toward industrial decarbonization

The industrial sector plays an important role in India's economy and emissions. The sector's contribution to India's gross value added (GVA) stood at 25 percent in 2019 (World Bank 2022). The industrial sector emitted 803 million metric tons CO_2 equivalent ($MMtCO_2e$), which represented approximately 30 percent of the national emissions in 2019 (MoEFCC 2023). Without additional decarbonization policies, the sector's emissions could triple by 2050 to approximately 50 percent of national emissions (Figure 1).

Emerging international regulations are likely to impact the competitiveness of carbon-intensive industries. Implementation of the Carbon Border Adjustment Mechanism (CBAM)[1] by the European Union is likely to increase fuel costs by 10 percent for heavy industries in India and decrease export earnings by 2.41 percent (Grover et al. 2023). Industrial decarbonization is, therefore, critical for meeting India's 2070 net zero target and development goals.

In 2019, energy use accounted for 73 percent of industrial sector emissions; process-related emissions—which result from chemical or physical transformations and processes—accounted for the remaining 27 percent. The chemical and cement sectors are leading contributors to process-related emissions, accounting for 64 percent of emissions. The techno-economic challenges in mitigating process-related emissions make it hard to abate the industrial sector.

CONTENTS

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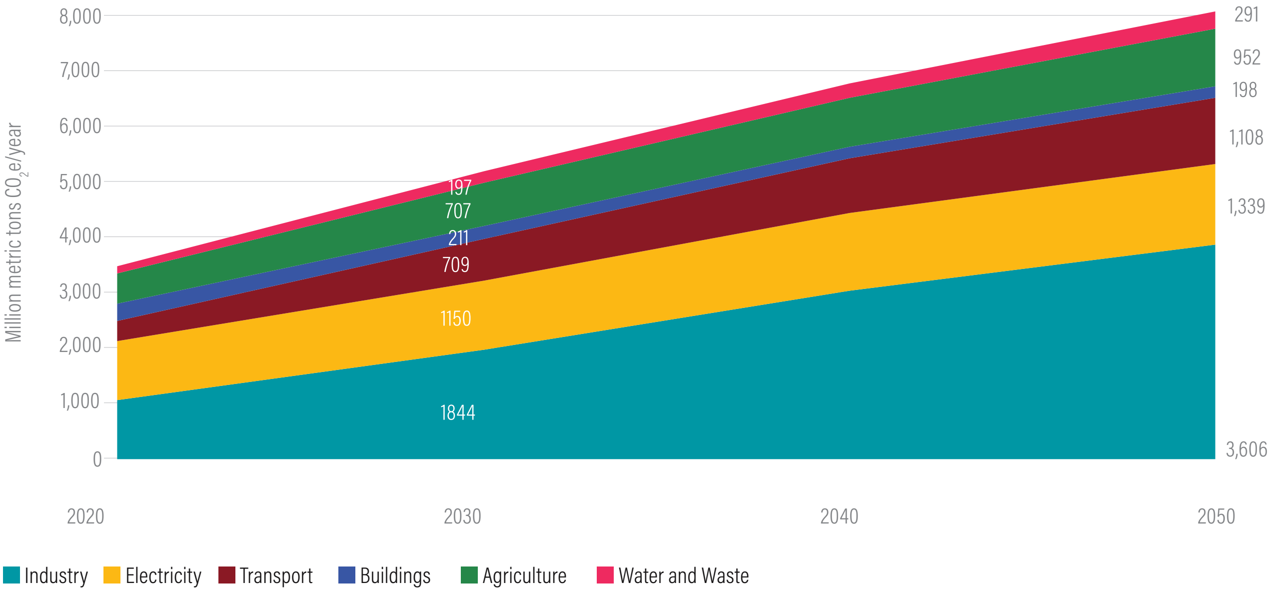
Expert notes provide timely, focused, and concise information for urgent challenges, based on expert perspectives.

FIGURE 1 | **India's projected greenhouse gas emissions by sector, assuming no additional decarbonization policies**

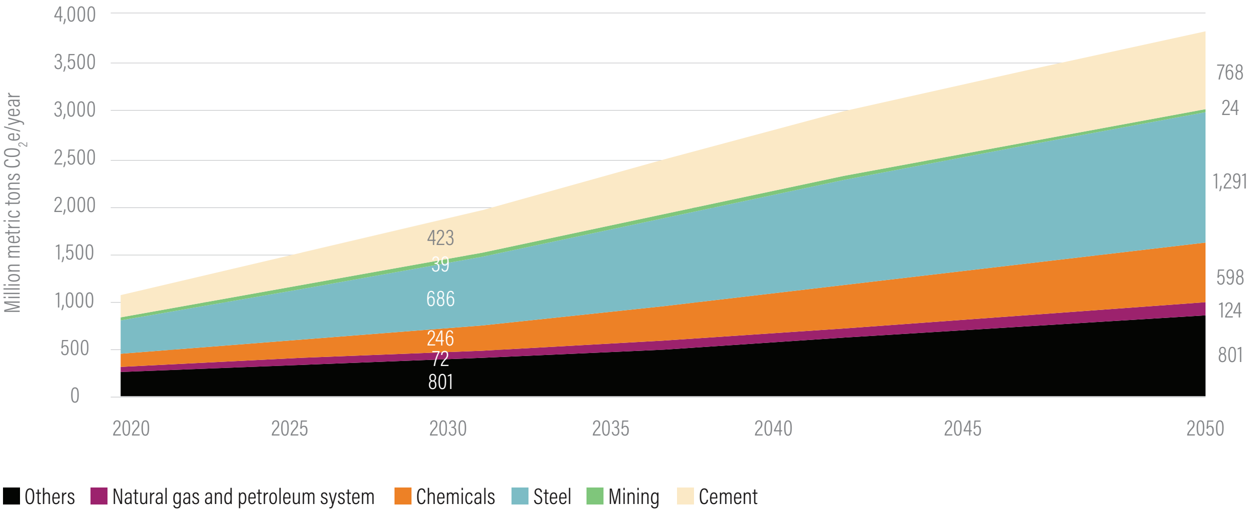


Note: Emissions from the electricity sector are nearly constant between 2020 and 2050 because the increase in demand for electricity is balanced by the rise in the share of nonfossil capacity in electricity generation.

Source: WRI authors, based on Swamy et al. (2021a).

In 2019, the combined emissions from the steel, cement, and chemicals sectors[2] reached 678 $MMtCO_2e$, which represented approximately 68 percent of the total industrial sector-related emissions (MoEFCC 2023). The growing demand from infrastructure development, housing, and transport, is expected to more than triple steel production (IBEF 2023) and double cement production (Kumar 2023) by 2050. Similarly, fertilizer demand is projected to almost double to 60 million tonnes by 2050 (FAI 2019). Under a reference scenario[3] that assumes no additional decarbonization policies, emissions from steel, cement and chemical sectors could grow to 2,657 $MMtCO_2e$ by 2050, which would account for approximately 74 percent of the total industrial sector emissions (Figure 2). This emissions growth makes these sectors integral to India's industrial decarbonization strategy.

FIGURE 2 | **Projected subsector emissions from the industrial sector, assuming no additional decarbonization policies**



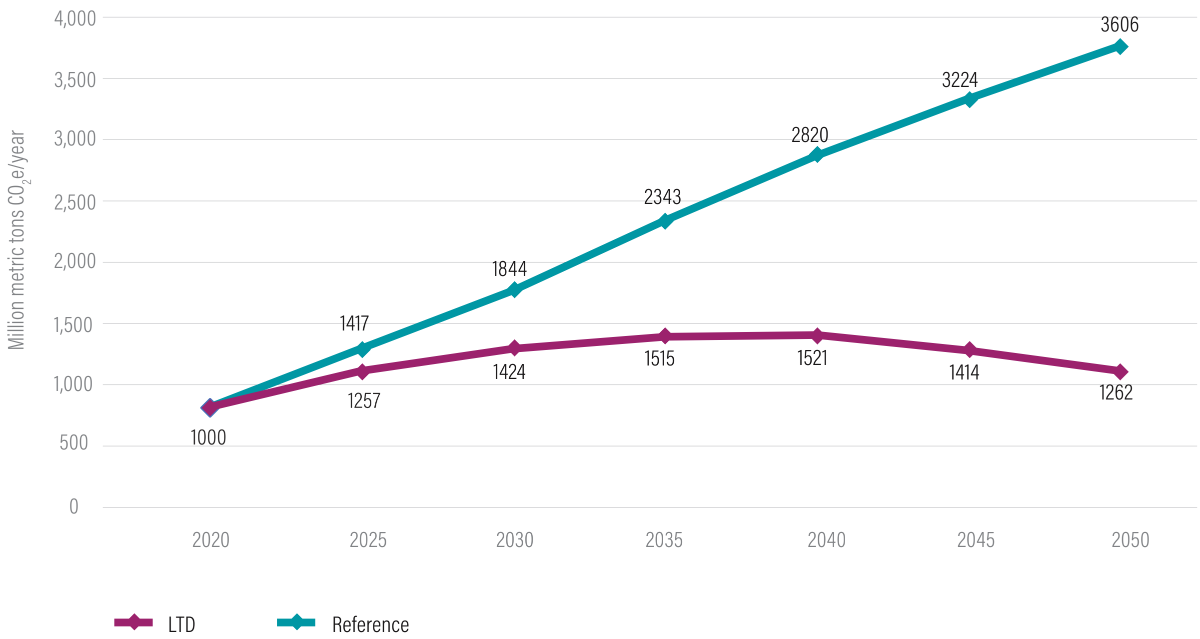
Source: WRI authors, based on Swamy et al. (2021a).

LEVERS FOR INDUSTRIAL DECARBONIZATION

This expert note discusses key policy actions to enable industrial decarbonization,[4] by examining the emissions reduction potential for the industrial sector in the long-term decarbonization (LTD) scenario (Swamy et al. 2021a) aligned with India's net zero 2070 target. A 7.8 percent compound annual growth rate (CAGR) for real gross domestic product (GDP) has been assumed for this analysis between 2020 and 2050, aligned with India's Viksit Bharat target of becoming a US$30 trillion economy by 2047 (MEA 2024). The scenario was created using the India Energy Policy Simulator (EPS).[5] The full structure and assumptions of the model are detailed in a technical note that WRI published in 2021 (Swamy et al. 2021b).

Under the LTD scenario, industrial emissions will be 65 percent lower than those in the reference scenario by 2050 (Figure 3). Further, cumulative industrial emissions decrease by 29,388 MMtCO_2e between 2020 and 2050 relative to the reference scenario. Four critical policy actions contribute to these emissions reductions (Table 1).

FIGURE 3 | Industrial emissions under the LTD and reference scenarios

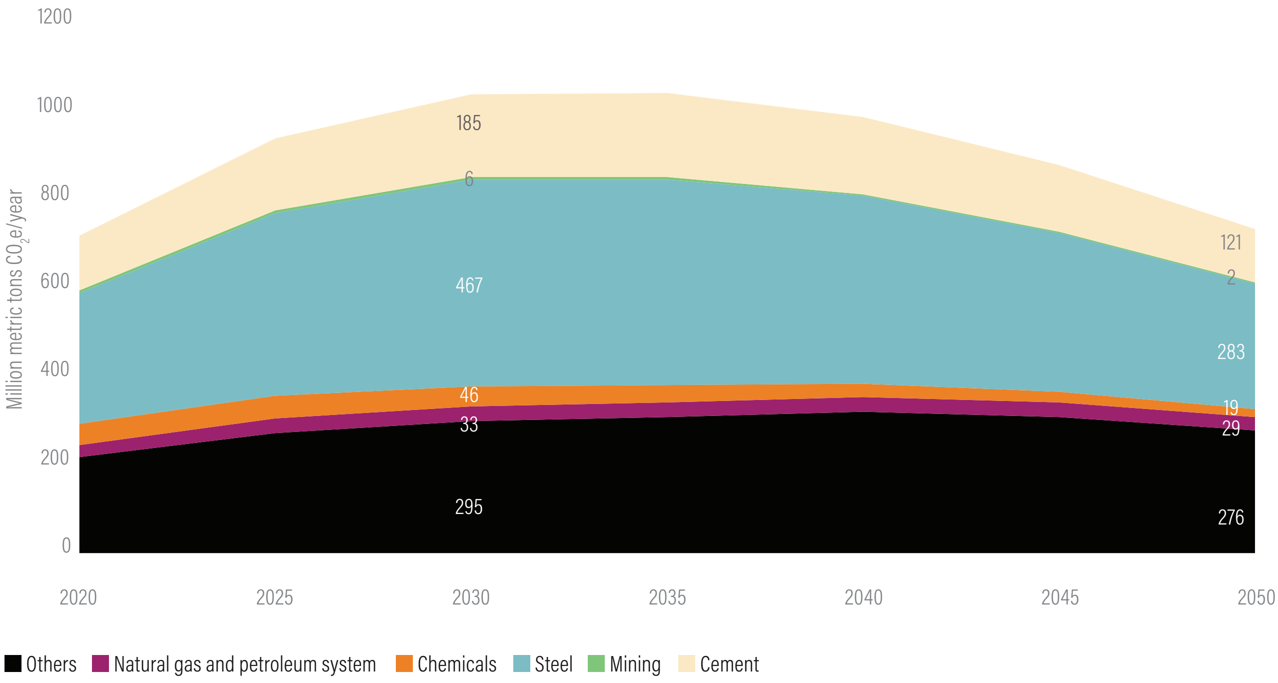


Note: LTD = long-term decarbonization.

Source: WRI authors based on Swamy et al. (2021b).

In 2050, the shares of energy-related and process-related emissions in total industrial sector emissions are projected to be 58 percent and 42 percent, respectively. Energy-related emissions (Figure 4) decline at a faster pace than process-related emissions (Figure 5), driven by an increase in the share of nonfossil-based electricity generation. The share of process-related emissions in total emissions increases over time. The chemical and cement sectors account for 68 percent of process-related emissions under the LTD scenario in 2050. Therefore, sector-specific pathways need to be identified to mitigate these emissions.

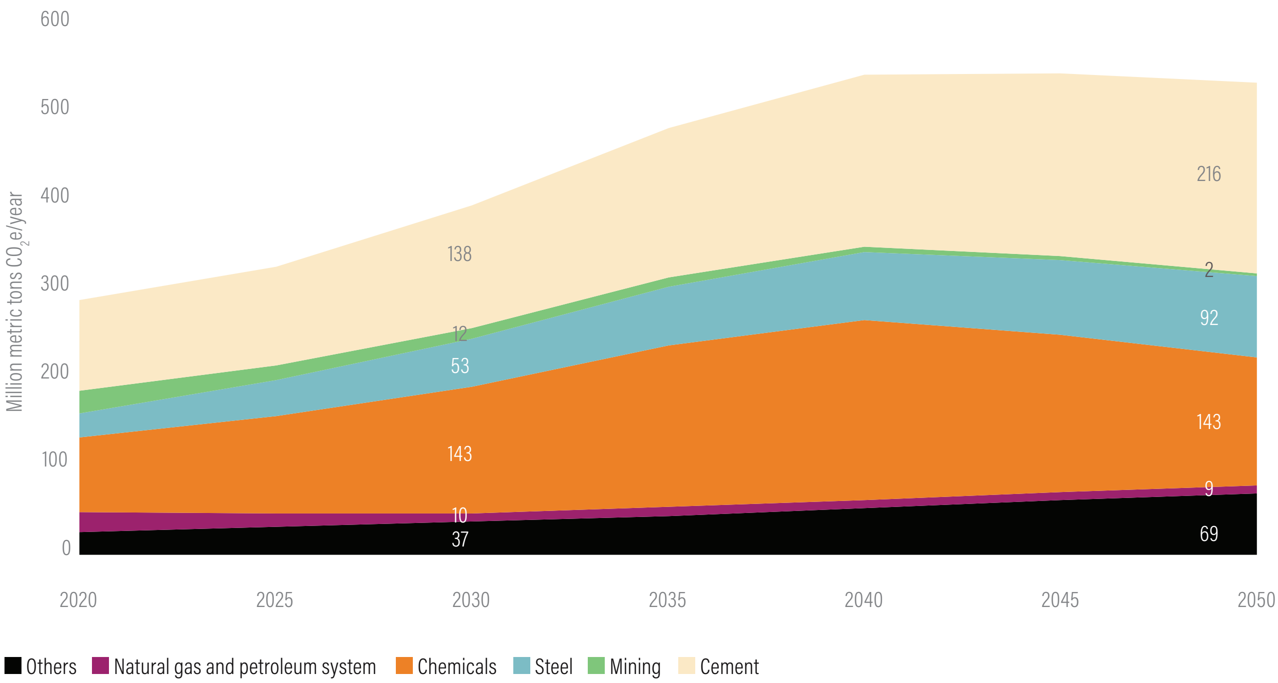
FIGURE 4 | Projected energy-related emissions in industrial subsectors under LTD scenario (2020–2050)



Note: LTD = long-term decarbonization.

Source: WRI authors, based on Swamy et al. (2021b).

FIGURE 5 | Projected process-related emissions in industrial subsectors under the LTD scenario (2020–2050)



Note: LTD = long-term decarbonization.

Source: WRI authors, based on Swamy et al. (2021b).

TABLE 1 | Key policy drivers for the industrial sector decarbonization in LTD scenario

PARAMETER	2050		CONTRIBUTION TO CUMULATIVE INDUSTRIAL EMISSIONS REDUCTION 2020–2050 ($MMTCO_2E$)
	Reference	LTD	
Industrial electrification and the hydrogen mandate (Percentage substitution of fossil fuels for the sector starting from 2025)	0	50%	12,367 (42%)
Industrial energy efficiency mandate (Average annual improvement in the specific energy consumption percentage)	0.4%	1.3%	4,606 (16%)
Material efficiency mandates (Demand reduction for emissions-intensive goods, relative to the reference scenario)		Cement: 15% Iron and steel: 20%	3,546 (12%)
Carbon price (Per tonne of CO_2 in all industrial subsectors)	0	US$ 50	2,945 (10%)
Others[a]			5,924 (20%)
SUPPORTING POLICIES			
Nonfossil electricity generation (%) (The share of nonfossil electricity generation in total electricity generation.)	68%	93%	
Hydrogen production via electrolysis (%) (The share of green hydrogen in total hydrogen production. Linearly increasing from 0% in 2025)	0%	100%	

Notes: Unless otherwise noted, a policy is linearly implemented starting from zero in 2020 to reach the specified policy setting in 2050. The [a]"Others" category includes policies on co-generation and waste heat recovery, F-gas-related measures, improved system design, early retirement of inefficient industrial facilities, and methane-related measures.

Note: LTD = long-term decarbonization

Source: WRI authors, based on Swamy et al. (2021b).

INDUSTRIAL ELECTRIFICATION AND HYDROGEN MANDATES[6]

The phased electrification and hydrogen mandates aim to replace fossil fuels (coal, natural gas, petroleum, fuel oil, and petcoke) used to generate heat in the production process with electrification and hydrogen. Implemented from 2025 onward, increasing linearly, it replaces up to 50 percent of fossil fuels by 2050. This policy lever could reduce cumulative industrial emissions by approximately 12,367 $MMtCO_2e$ (42 percent) between 2020 and 2050. However, technologies such as electric kilns, electric crackers, and thermal heat batteries are under development, and they are cost-intensive, especially for high-temperature processes in the cement and steel sectors (Vine 2021).

Green hydrogen has the potential to serve as a promising alternative for high-temperature industrial applications where electrification may not be suitable (Li et al. 2024). The Ministry of New and Renewable Energy (MNRE) under the National Green Hydrogen Mission (NGHM) has announced a target of

5 million metric tonnes per annum by 2030 (MNRE 2023). The demand from the industrial sector for hydrogen as a fuel could increase to 22 million tonnes (MT) in 2050 in the LTD scenario (Swamy et al. 2021a).

In the cement industry, hydrogen-based injections can partially replace fossil fuels to produce the high temperatures required in the kiln. In the steel and chemical sectors, hydrogen also has the potential to replace feedstocks such as coal or gas. The cost of green hydrogen, US$4.10–7/kg, is significantly higher than the cost of gray hydrogen, which is US$2–2.75/kg at present (Godrej 2023). However, the cost of hydrogen electrolyzers could decline by 48 percent by 2050 due to economies of scale[7] (Swamy et al. 2021b). The hub-based model proposed in the NGHM for co-locating green hydrogen producers and end-use industrial sectors can help incentivize investments in green hydrogen and promote economies of scale (MNRE 2024a).

INDUSTRIAL ENERGY EFFICIENCY

Industrial energy efficiency is a relatively low-cost and readily available measure[8] for reducing emissions. An average annual improvement in specific energy consumption of 1.3 percent is estimated to reduce cumulative emissions by 4,606 $MMtCO_2e$ (16 percent) between 2020 and 2050.

Energy efficiency measures have a limited role in cement[9] and chemicals sectors because 60–65 percent of the total emissions in these sectors are process-related emissions, unlike the steel sector, where 93 percent of emissions come from energy use[10] (Swamy et al. 2021a). The average specific energy consumption of Indian steel is 6–6.5 gigacalories per tonne of crude steel (Gcal/tcs), compared to the global average of 4.5–5.0 Gcal/tcs (Ministry of Steel 2021), despite the improvements under the Perform, Achieve, and Trade (PAT)[11] scheme. Adoption of technologies[12] such as coke dry quenching, top-pressure recovery turbines, slag heat recovery, and cogeneration will be important for further improving this sector's energy efficiency (CII 2021).

MATERIAL EFFICIENCY MANDATES

Material efficiency mandates will be critical for mitigating process-related emissions, which will be achieved by reducing the demand for new construction materials by promoting recycling and increasing the lifespan of existing products. Our estimates suggest that material efficiency and recycling mandates[13] for cement and steel could reduce cumulative emissions by 3,546 $MMtCO_2e$ (12 percent) in the industrial sector between 2020 and 2050.

In the steel sector, the Steel Scrap Recycling Policy and the Vehicle Scrapping Policy have been introduced to enhance material circularity. However, import of ferrous scrap used in steel manufacturing was high, approximately 9.8 MT (30 percent of India's total scrap consumption) in 2022–23 (Steel Mint 2023). Limited scrap availability remains a significant challenge.

As for the cement sector, there is a need to implement strategies to reduce the use of clinker in cement, cement in concrete, and concrete in structures (Habert et al. 2020). Measures such as prolonging building lifespans and recycling construction waste are critical to promote resource efficiency, and they have significant potential to be scaled up.[14]

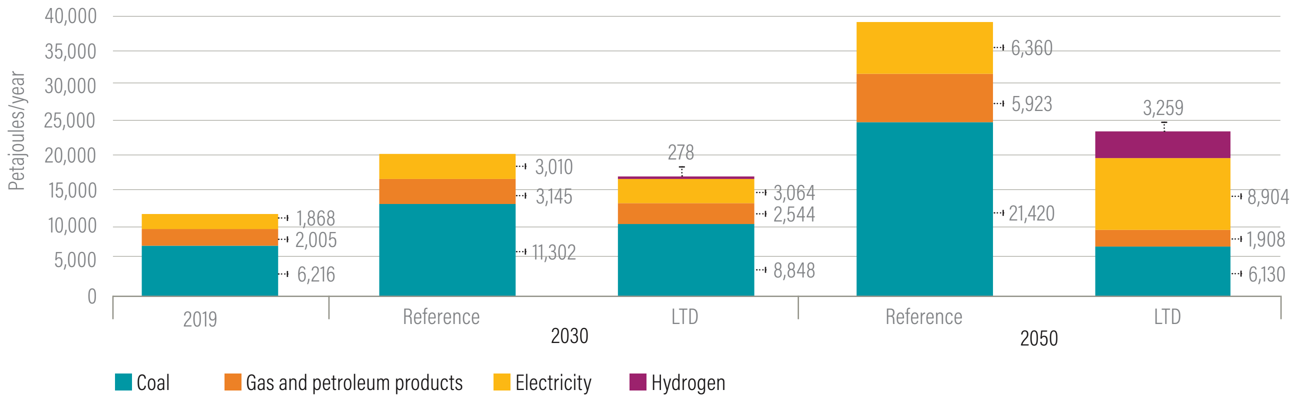
CARBON PRICE

Carbon pricing puts a price on emitting carbon by levying a fee on emissions and/or incentivizing emissions reductions (UNFCCC n.d.). It can be implemented as a tax or a market mechanism. A carbon price modelled at approximately US$4/tonne CO_2 (equivalent to the coal cess[15]) in 2019 and increasing linearly to US$50/tonne CO_2 in 2050 could reduce cumulative emissions by 2,945 $MMtCO_2e$ (10 percent) between 2020 and 2050. However, the effectiveness of a carbon pricing mechanism depends on its design. At the same time, there may be distributional impacts, especially for smaller firms or low-income households, that will need to be considered.[16]

India's proposed National Carbon Market (NCM) intends to prescribe emissions intensity targets[17] for nine sectors, including the iron and steel, cement, and fertilizer sectors, allowing the carbon price to be discovered in the trading market (BEE 2024). These reduction targets must be ambitious to encourage abatement and incentivize investment in low-carbon technologies (Hingne et al. 2023).

POLICIES FOR ENABLING CARBON CAPTURE, UTILIZATION, AND STORAGE (CCUS) DEPLOYMENT

FIGURE 6 | Projected industrial fuel mix (2019, 2030, 2050)



Note: LTD = long-term decarbonization.

Source: WRI authors, based on Swamy et al. (2021b).

Despite measures in the LTD scenario, the industrial sector could still rely on fossil fuels to meet almost 50 percent of its total fuel demand (Figure 6). CCUS technology is likely to be required to abate residual emissions and process-related emissions from the cement and chemicals sectors. To make CCUS commercially feasible, the challenges of high capital costs, limited information on geological storage sites, lack of feasible use cases, and insufficient infrastructure need to be addressed.[18]

RECOMMENDATIONS

India's Long-Term Low-Carbon Development Strategy 2022 highlights the industrial sector as a focus area (MoEFCC 2022b). Process emissions, high costs, and the uncertainties of low-carbon technologies remain prominent challenges for the sector. We offer six recommendations to enhance industrial decarbonization in India:

- **Increase support for low-carbon technologies such as green hydrogen and CCUS:** Storage and transportation infrastructure are key to utilizing hydrogen technologies. Co-locating green hydrogen producers and end users—steel, chemicals, and cement industries—in "hubs" can enable sharing of financial and operational risks (Nallapaneni and Jain 2023). Mechanisms such as sovereign green bonds, blended finance, and government incentives can be explored to provide long-term funding for hydrogen hubs.

  A comprehensive study to map potential geological storage sites and assess the techno-economic feasibility of carbon utilization is required to improve CCUS adoption. Institutional frameworks and grants to support CCUS projects across the full project/funding cycle through incentives such as tax and cash credits need to be developed (NITI Aayog 2022). Setting up CCUS projects in clusters or hubs would reduce costs and de-risk projects across the value chain (Global CCS Institute 2024). The Article

6.4 mechanism of the Paris Agreement could be explored as a potential avenue for financing CCUS projects (UNFCCC 2024). The Ministry of Environment, Forest and Climate Change (MoEFCC) has notified that CCUS should be considered for trading under the Article 6.4 mechanism (MoEFCC 2024).

- **Scale up demand-side policies:** Demand-side interventions such as material efficiency and circularity, along with harmonized standards for green products, will be required where supply-side interventions are limited (MoEFCC 2022b).
  Policies and initiatives such as the National Circular Economy Roadmap, and Construction and Demolition Waste Management (CDWM) have been announced to promote material efficiency. For the effective implementation of existing policies, adequate recycling infrastructure, in addition to the creation of systems and incentives for the uptake of recycled materials, is required (Roy Chowdhury et al. 2020). Lowering the Goods and Services Tax on scrap from 18 percent to 5 percent (Arora 2023) will incentivize the formalization of the recycling sector. The establishment of standards will also ensure collection of high-quality scrap.

  Interventions such as public procurement mandates will be required to create demand for green materials such as green steel and cement.

- **Incentivize and support decarbonization in micro, small, and medium enterprises (MSMEs):** Despite their economic contribution,[18] MSMEs face challenges in accessing finance for the uptake of low-carbon technologies, largely due to the higher perceived risks of lending, high transaction costs, and lack of awareness (TERI 2022). Only 16 percent of MSMEs are financed through the formal banking system (Upadhyay 2022).

  Awareness of, and access to, existing public financing schemes and additional mechanisms such as credit guarantee schemes (MoMSME 2024a), special credit mechanisms (MoMSME 2024b), and aggregation models could lower transaction and monitoring costs (Goenka et al. 2024). Initiatives such as the Promising Lenders Fund can be modified to help non-banking financial corporations direct capital toward required technologies, incentivizing private sector investments. Designing the National Carbon Market and the upcoming Voluntary Carbon Market to incentivize emissions reductions from the MSME sector can play a key role in financing low-carbon interventions at scale.

- **Promote indigenous manufacturing of low-carbon technology components:** Promoting domestic manufacturing of low-carbon technology components is necessary to reduce import dependency, create green jobs, and compensate for the jobs lost in brown manufacturing. Domestic manufacturing of low-carbon technology components such as electrolyzers, solar PVs, energy storage systems, and batteries is currently limited. Scaling up the production-linked incentive (PLI) schemes and funding support for hydrogen production and pilot projects under the NGHM can help promote indigenous manufacturing (MNRE 2024b).

- **Develop a robust research and development (R&D) ecosystem to demonstrate and scale nascent technologies:** As decarbonization technologies are at varying stages of development, financing support will need to be designed based on a technology readiness levels (TRLs). For example, in the steel sector, technologies like scrap-based production may require instruments such as blended debt financing in order to scale. Nascent technologies such as green-hydrogen-based steelmaking may require instruments such as development equity funds (Kashyap and Purkayastha 2024).

- **Develop a skilled workforce:** As the sector decarbonizes, there will be increased demand for skilled labor, especially to operate newer technologies and drive research and innovation in technology development. Reskilling and upskilling the existing workforce employed in fossil-dependent sectors should be prioritized. Early and concerted investments in targeted training, curriculum updates, apprenticeships, and upskilling programs at scale are necessary to drive the low-carbon transition in the Indian industrial sector. In 2023, the female labor force participation rate in India was 33 percent, compared to the global average of 49 percent (World Bank 2023). To ensure just transition, innovative gender-inclusive skilling models responding to fast-evolving technology changes need to be designed. Enhancing labor productivity in the MSME sector will also be critical (White and Madgavkar 2024).

ENDNOTES

1. The implementation of a national carbon credit mechanism could reduce the adverse impacts of the CBAM. The amount of carbon price paid domestically—in the form of a carbon tax or through a carbon market—would be eligible for a rebate under the CBAM.
2. Emissions from the chemicals sector include emissions from the fertilizer sector. This is for alignment with the model structure of the India Energy Policy Simulator (EPS), which includes the fertilizer sector within the chemicals sector.
3. The reference scenario accounts for decarbonization policies implemented up to 2020. This does not currently include the Indian carbon market mechanism (BEE 2024) because the targets have not yet been announced. However, the reference scenario does incorporate existing energy efficiency mechanisms such as PAT. If the Indian carbon market is designed to be more ambitious than the existing policies, it could prompt further emissions reductions from the industrial sector.
4. The following subsectors within the industrial sector are represented in the model: iron and steel, cement, chemicals, mining, petroleum and gas, and others. The chemicals sector in the EPS includes the fertilizer sector.
5. The EPS is an open-access, system dynamics model. Link to the online interface: https://india.energypolicy.solutions/.
6. The electrification mandate covers both grid and captive power plants. This mandate covers low-to-medium-heat and high-heat applications. For low-to-medium-heat applications, industrial fossil fuel consumption is shifted to electrification. For high-heat applications, a shift to green hydrogen is modeled.
7. The projected cost reductions are based on R&D learning rates estimated using data from the International Energy Agency (IEA 2020). The decline in costs is due to economies of scale, a decline in input costs, and improvements in efficiency.
8. India's energy intensity across all sectors improved by 2.2 percent between 2010 and 2020. However, to align with the Voluntary Action Plan on Doubling the Rate of Energy Efficiency Improvement by 2030, the annual energy intensity improvement rate would need to increase to 4.6 percent in the next decade (Goenka et al. 2024).
9. The Indian cement sector is among the most efficient in the world. The global average specific thermal energy consumption is 3.5 GJ/tonne of clinker compared to the Indian average of 3.1 GJ/tonne of clinker (Bhardwaj et al. 2020).
10. Of the total 93 percent of energy-related emissions from the steel sector, 84 percent are from thermal energy and 8 percent from electrical energy.
11. In PAT Cycles-I, II, and III (2012–2020), designated consumers in the iron and steel, cement, and chemicals sectors achieved energy savings of 4.23 million tonnes of oil equivalent (Mtoe), 3.19 Mtoe, and 1.39 Mtoe, respectively (MoEFCC 2022a).
12. Technologies such as oxy-fuel combustion and regenerative burners can also be deployed to improve the efficiency of boilers and furnaces.
13. The policy setting on the material efficiency mandate leads to a reduction in demand for cement (Shukla et al. 2015), iron and steel (Hall et al. 2020), and water and waste management services (Ministry of Jal Shakti 2021), by 15 percent, 25 percent, and 20 percent, respectively. For the cement sector, this policy reduces demand for the selected materials through measures such as compact urbanization patterns, use of low-energy and local materials, mixing of fly ash in cement, and recycling and reuse of industrial and construction waste. A conservative setting is assumed because most of the infrastructure is yet to be built in India's current development trajectory. For the steel sector, resource efficiency measures are assumed to be actively implemented. For the water and waste sector, measures such as integrated water resource management and improvement of water use efficiency through regulatory mechanisms are assumed to be implemented.
14. India has a recycling capacity of approximately 6,500 tonnes per day at present, which is just 1.3 percent of the total construction and demolition waste generated (Roy Chowdhury et al. 2020).

15. The coal cess was implemented in 2010 under the Finance Act of India. The cess has been levied at INR 400 per tonne of coal production and imports. The cess was levied to finance clean energy and clean environment initiatives. Since 2017, the cess has been subsumed under the Goods and Services Tax (GST) (Banerjee and Nandan 2024).
16. For example, a US$40 national carbon price implemented in the transport and electricity sectors, could lead to an increase in the expenditure of low-income households by an average of 4.5 percent if their current consumption patterns are maintained (Steckel et al. 2021).
17. Setting targets at the company level (instead of the facility level) can provide more flexibility in reducing emissions, and cut administrative and compliance costs.
18. Capital costs for carbon capture facilities are significant, and are currently in the range of US$87–250 million for industrial applications (NITI Aayog 2022). The total carbon capture cost per tonne of CO_2 is estimated to be US$22–31 for cement (2.5 million tonnes per annum [mtpa] clinker), US$43–45 for steel (2.0 mtpa blast furnace-blast oxygen furnace [BF-BOF] integrated steel plant), and US$25–31 for natural-gas-based production of hydrogen for use in the chemicals sector (NITI Aayog 2022). The energy consumed by MSMEs is 20–25 percent of the energy consumed by large industries (Trivedi and Jena 2022)

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ABOUT WRI INDIA

WRI India, an independent charity legally registered as the India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. Our work focuses on building sustainable and liveable cities and working towards a low carbon economy. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the earth, promote livelihoods, and enhance human well-being. We are inspired by and associated with World Resources Institute (WRI), a global research organization. Know more: www.wri-india.org.

Our challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to inform government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.